Background Discussion of Model Input Data and Potential Refinements

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Table of Contents Page

Abstract 1

1. Background and reasons for this paper 2

2. Background to improved inputs in the State & EPA MOU protocol 5

3. Unique aspects of the enhanced RUC2 weather data 10

4. Upgraded CALMET inputs 13

5. Upgraded CALPUFF inputs 16

6. Upgraded SO2 emission rates 18

7. Recommended MOU protocol updates 20

8. Tabulation of modeled concentrations 29

9. CALPUFF results accuracy tests 30

10. Another method for calculating air quality deterioration 33

11. Comments 37

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Abstract

Air quality modeling protocols explain models of choice, describe model inputs and describe tabulation of modeled concentrations when using the models to assess probable air quality – in this case over Clean Air Act (CAA) Prevention of Significant Deterioration (PSD) Class I areas. Four sulfur dioxide (SO2) modeling protocols involving the CALMET and CALPUFF models were used and reported in 2002 and 2003 – two by the North Dakota Department of Health [1] on behalf of the State of North Dakota and two by Region 8 of the U.S. Environmental Protection Agency (EPA). [2]

Public hearings were held in May 2002 and June 2003 on legal and technical aspects of the department's 2002 and 2003 modeling protocols. During these hearings, another protocol was advocated by ENSR Corporation on behalf of Basin Electric Power Cooperative. These protocols, EPA's draft modeling reports, and other exhibits in the hearings' docket were reviewed.

Some elements of the State's 2003 protocol have been improved in an alternate modeling protocol. This protocol represents one step in a process for resolving differences between State and EPA Region 8 modeling protocols. The process was established through a State and EPA Memorandum of Understanding (MOU) dated February 24, 2004. [3] The alternate modeling protocol was verbally approved by EPA on April 28, 2004. This document supplements reports describing the alternate protocol and results of execution of this protocol with descriptions of improvements to the State's 2003 protocol, and it presents a few recommended refinements for a future protocol.

[1] Exhibit 81 from the department's June 2003 hearing, which is titled "Calpuff Analysis of Current PSD Class I Increment Consumption in North Dakota and Eastern Montana Using Actual Annual Average SO2 Emission Rates."

[2] Exhibit 84 from the department's June 2003 hearing, which is titled "Dispersion Modeling Analysis of PSD Class I Increment Consumption in North Dakota and Eastern Montana."

[3] The MOU is Tab "A" of North Dakota's SO2 PSD Air Quality Modeling Report.

1. Background and reasons for this paper

CALMET and CALPUFF are EPA approved computer codes that are executed in tandem. User's are required to provide a variety of input data that are used by the models. These inputs include values for user computational control variables, weather and precipitation data, geophysical data and source emissions data. Some CALMET output data, such as space and time interpolated wind fields for points on a Cartesian grid, are required by CALPUFF. The scale of the grid domain is 640 kilometers west to east and 460 kilometers south to north over eastern Montana and western North Dakota. [4] CALPUFF output includes concentrations in math units of micrograms per cubic meter (ug/m3) at user specified ground level receptors within the grid.

A modeling protocol identifies and explains user chosen computational control input data, weather and precipitation data, geophysical data and source location and emissions data. The protocol also explains the methods for tabulation of modeled concentrations for assessment of compliance with Clean Air Act (CAA) health standards and CAA PSD increments.

The purpose of this document is to describe enhancements to the State's 2003 modeling protocol when constructing the MOU alternate modeling protocol. Year 2003 State and EPA Region 8 protocols are revisions of respective year 2002 protocols subsequent to the department's 2002 hearing process and EPA's 2002 concurrent public comment period. Settings and values for CALMET and CALPUFF input variables, as well as other data, are provided in the 2003 protocols.

One objective for the MOU alternate modeling protocol (hereafter MOU protocol) is to achieve State and EPA concurrence on all aspects of a modeling protocol. [5] The department prepared initial and revised drafts of the MOU protocol for EPA review. EPA provided comment on the sequential drafts of the MOU protocol during March and April 2004. The final MOU protocol adopted all EPA comment on those drafts, and EPA verbally approved it on April 28, 2004. [6]

Another objective for review of the 2003 protocols is to assure that modeling inputs, as well as modeling technique, are anchored to the CAA, PSD rule, interpretive regulation, and science.

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[4] The geographic location of the modeling domain is shown in figure 2-1 of Exhibit 81.

[5] During MOU or MOU protocol negotiations, EPA did not offer criteria by which it would deem a modeling protocol as acceptable. EPA's report "Comments on NDDOH's Proposed Determination Regarding the Adequacy of the SIP to Protect PSD Increments for Sulfur Dioxide," which is Exhibit 57 from the department's May 2002 hearing docket, EPA's 2002 and 2003 draft modeling reports and EPA correspondence were reviewed.

[6] The MOU protocol is Tab "B" of North Dakota's SO2 PSD Air Quality Modeling Report. The MOU protocol consists of two documents: "A proposed alternative air quality modeling protocol to examine the status of attainment of PSD Class I increments" which is dated April 30, 2004, and "Revisions to pages 39 and 40 in the proposed alternative air quality modeling protocol dated April 30, 2004," which is dated May 7, 2004.

Furthermore, some values or settings for model control-file variables as used in the State's 2003 protocol were changed for the MOU protocol so as to optimize harmony among input data and functions of the variables in the two models.

In addition, some sulfur dioxide emission rates were improved. New model inputs include enhanced RUC2 data,[7] as well as National Weather Service (NWS) meteorological data and ozone data for 2001 and 2002. So, modeled concentrations using the MOU protocol will not duplicate results of State or EPA Region 8 2003 protocols.

Lastly, the department has used air quality models and sulfur dioxide emissions data to estimate ambient sulfur dioxide concentrations in Theodore Roosevelt National Park (TRNP) and the Lostwood Wilderness Area since 1977. [8] Advances in models and in inventories of emitted sulfur dioxide occurred periodically during the intervening years. For example, the first use of a time dependant mesoscale model occurred in 1981-1982, [9] and the first sulfur dioxide emissions inventory of oil field flares and treaters was completed in 1987. The protocol improvements and first time uses of better data that have occurred since 1999 are listed for 2002, 2003 and 2004 below.

A. Year 2002

(1) modeled sulfur dioxide actual emissions (as defined by rule) rather than permit allowable emissions

(2) completed current and PSD baseline sulfur dioxide emissions inventories for flares and treaters in the oil and gas production fields of western North Dakota

(3) modeled inventories of current and PSD baseline inventories of sulfur dioxide emissions rather than increment affecting emissions, which capture source by source increases or decreases in emissions between the two time lines

B. Year 2003

(1) installed prognostic Meteorological Model (MM) weather data for 1990 and 1992 for advecting the emitted sulfur dioxide from sources

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[7] "RUC Analysis-based CALMET Meteorological Data for the State of North Dakota," dated August 24, 2004, by WindLogics, Inc., St. Paul MN. This document is also Tab "D" of North Dakota's SO2 PSD Air Quality Modeling Report.

[8] Exhibits 11, 24 and 25 from the department's May 2002 hearing. See also figures 2 and 3 in Exhibit 82 from the department's June 2003 hearing; these figures describe the historically evolving approach to use of emission rates in air quality modeling.

[9] Exhibits 22 and 23 from the department's May 2002 hearing.

(2) completed assimilation of 2000 hourly ozone data, hourly precipitation data, NWS hourly surface and NWS twice daily upper air (rawinsonde) observational data

(3) improved model receptor networks in PSD Class I areas

C. Year 2004

(1) installed enhanced RUC2 data for 2000, 2001 and 2002 for advecting the emitted sulfur dioxide from sources

(2) completed assimilation of 2001 and 2002 hourly ozone, hourly precipitation data, NWS hourly surface data and NWS twice daily upper air observational data

(3) improved inventory of emitted sulfur dioxide at PSD baseline (around 1977)

(4) completed model accuracy performance testing for each year of model input meteorological data using sulfur dioxide emission rates as actual emissions and as hourly CEM emissions (previously, such testing used one year of hourly CEM emissions with corresponding meteorology)

(5) used an alternate paired in space only method (which applies a baseline concentration as defined by rule) – in addition to EPA's paired in space and time method – for calculating 3-hour and 24-hour deterioration of modeled sulfur dioxide concentrations between PSD baseline and current time lines

In 2005, technically upgraded versions of the CALMET and CALPUFF models will be implemented. These versions may change model predicted sulfur dioxide concentrations.

2. Background to improved inputs in the alternate protocol

The State & EPA MOU acknowledges State discretion in application of several technical aspects of a modeling protocol under the MOU's subpart I. It also includes a provision for an EPA review for comment on department drafts of the alternate protocol under subpart III.

A. Subparts I and III of the MOU includes several legal and technical issues, such as:

(1) the efficacy of the enhanced RUC2 data in air quality modeling,

(2) baseline sulfur dioxide emission factors for electricity generating plants,

(3) baseline source normal operations and coal sulfur content,

(4) source sulfur dioxide emission rates, and

(5) methods for calculating baseline to current time deterioration of sulfur dioxide, including the modeling of an emission inventory for current time and another for PSD baseline and application of the "baseline concentration."

B. Subpart I of the MOU did not include all technical issues of concern to EPA. Additional issues that arose during EPA's review of drafts of the MOU protocol are:

(1) the purpose or role of model sensitivity tests,

(2) the magnitude of the background concentration for accuracy tests of model predicted sulfur dioxide concentrations,

(3) changes, if any, from baseline to current time in oxide constituents of coal and ash as a basis for adjusting sulfur dioxide emission factors, and

(4) inclusion of perimeter receptors for model receptor networks in some PSD Class I areas.

C. The MOU and the MOU protocol are continuing efforts by the department to resolve outstanding modeling, monitoring and legal issues with EPA as directed by the State Health Officer. [10]

D. Initially, the input values or settings of CALMET and CALPUFF control-file variables were tabulated as a side by side comparison from department and EPA

[10] Section 10.0 of the September 8, 2003, Order of North Dakota State Health Officer Terry L. Dwelle. This order is Tab "E" of North Dakota's SO2 PSD Air Quality Modeling Report.

Region 8 modeling results reports. [11] Subsequently, transcripts of the department's hearings in 2002 and 2003 and exhibits in the docket for the two hearings were examined, as well as user's guides for the CALMET and CALPUFF models [12] and portions of the model executable codes.

E. Respective State and EPA Region 8 2003 protocols applied deviations from IWAQM recommended input values or settings for some model control-file variables. IWAQM's recommendations are not applicable in all instances, as noted by the Region in its 2002 and 2003 draft reports. [13]

F. In 2001-2002, EPA Region 8 followed the State's earlier modeling in 1999 [14] and used the same settings or values for most CALMET and CALPUFF input variables; but its 2003 modeling did not use the State's 2003 settings or values for variables such as DGRIDKM, NZ, TERRAD, R1, R2 and IVEG.

G. Year 2003 protocols did not explain the reasons for some chosen values or settings of model input variables; for example, values for CALMET input variable ZFACE and CALPUFF input variables XLAT and IVEG. (See sections 4 and 5.)

H. Some values and settings in 2003 protocols are not optimum choices, such as the x:y coordinates of emission units within industrial plants, the initial

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[11] Complete lists of CALMET and CALPUFF control-file input variables are provided in Appendices A and B, respectively, of the Interagency Workgroup on Air Quality Modeling (IWAQM) "Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts." The IWAQM report is Exhibit 29 in the docket for the department's May 2002 hearing.

In addition, users guides and executable codes for these models should be consulted, as some changes or updates to the codes have occurred since 2000.

[12] "A User's Guide for the CALMET Meteorological Model," Version 5, by Earth Tech, Inc., Concord MA, dated January 2000.

"A User's Guide for the CALPUFF Dispersion Model," Version 5, by Earth Tech, Inc., Concord MA, dated January 2000.

[13] For example, "Had the IWAQM defaults been used in the State's limited performance evaluation, it appears that model performance would have been degraded, with the model exhibiting a bias toward overprediction." Page 15 of Exhibit 84 from the department's June 2003 hearing.

[14] Draft "Calpuff Class I Area Analysis for Milton R. Young Generating Station," by the North Department of Health and dated May 24, 1999. This draft Calpuff analysis was never finalized as illustrated by the two letters below.

(1) Letter by Francis J. Schwindt, Chief, Environmental Health Section, State Department of Health, dated Mar 13, 2001, to Richard R. Long, Director, US EPA, Region 8, summarizing a meeting with US EPA, Region 8, held on January 10, 2001.

(2) Letter by Richard R. Long, Director, Air and Radiation Program, US EPA, Region 8, dated Mar 28, 2001, to Francis J. Schwindt, Chief, Environmental Health Section, State Department of Health, summarizing EPA's view, etc., of the meeting held on January 10, 2001.

horizontal plume widths at stack tops (variable SIGMAYI), the reference latitude for the center of the source–receptor domain (variable XLAT), and the boundaries of the CALPUFF computational domain. (See section 6.)

I. Furthermore, the State and EPA Region 8 did not use the same meteorological data with their respective 2003 protocols. The department used six years of NWS observational data, and EPA Region 8 used five years. The department also used 1990 MM4 and 1992 MM5 prognostic data in conjunction with NWS observational data. [15] EPA used 1994 MM5 data, as well as the 1990 MM4 and 1992 MM5 data. [16] And, the values for CALMET input variables IEXTRP (i.e., –4), R1 and R2 were the same whether using only NWS observational data or using MM prognostic data in conjunction with NWS observational data; no written explanations were given. (See sections 3 and 7.1.)

J. EPA Region 8 compared modeled sulfur dioxide concentrations when using NWS observational weather data with and without MM prognostic weather data. [17] It concluded ". . . it is evident there was very little change in overall concentrations between the two results." ". . . the overall change was insignificant." [18] EPA did not explain this outcome in the context of differences in the spatial and temporal resolution of the NWS observations and of the MM5 prognostic data. For example, the NWS upper air (rawinsonde) data are available only every twelfth hour; these data are obtained only at Bismarck and Glasgow within the modeling domain. The average distance between NWS surface weather stations, which measure hourly surface meteorological data, within the modeling domain is 135 kilometers. [19] (See sections 3 and 7.1.)

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[15] Section 2.2.4 in Exhibit 81 from the department's June 2003 hearing. The MM4 and MM5 data sets were provided by Tim Allen, F&WS, Denver, CO; the department has no documentation for these data sets. The MM5 data set is in the MM4 format suitable for ingest by CALMET. Thus, CALMET variable IPROG is set to 4 for both sets.

"MM4 is . . . old and outdated . . . and is no longer supported by its developers." (Supplemental Written Testimony of Walter A. Lyons, which is Tab "D" in Volume 5 of Exhibit 95 from the department's June 2003 hearing. Page 12.)

[16] Page 7 in Exhibit 84 from the department's June 2003 hearing.

[17] Section 2.1.3 in Exhibit 84 from the department's June 2003 hearing.

[18] Id. No criteria were provided so as to ascertain when differences would be significant.

[19] For example, figure 2-2 in Exhibit 81 from the department's June 2003 hearing or page 9 in the MOU protocol.

K. One witness at the May 2002 hearing stated that documentation of model sensitivity and diagnostic tests conducted by the department was incomplete. [20] This witness also stated that calibration of models by sensitivity testing with monitoring data should be avoided. [21] Although empirical validation allows adjustments through reassessment and confirmation of model outputs with observations, [22] results of most tests, although useful, were set aside for the MOU protocol, except results for CALPUFF input variable MDISP. [23] (See sections 8 and 9.)

L. No hearing comments were given on the department's CALMET code modification regarding application of values for the BIAS variable. [24] However, EPA Region 8's 2002 draft report describes the code modification by the department and indicates that the modification is technically sound, but it did not use the modification in its modeling. [25]

M. The State and EPA Region 8 used different rates of emitted sulfur dioxide with their respective 2003 protocols. The State used actual emissions as defined by rule (total annual emissions during operating hours). The Region used the 90th percentile of hourly CEM rates as a peak rate for major sources (except those sources retired after PSD baseline). [26] The different rates contributed to significant differences in modeled sulfur dioxide deterioration. (See sections 6, 7.2 and 7.3.)

N. Finally, EPA Region 8 did not include a model accuracy performance analysis of its model inputs with its 2002 and 2003 protocols. [27] Its 2002 draft report

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[20] Testimony by Richard Londergan, Earth Tech Inc., Concord, MA. Transcript of Hearing held May 6, 7 & 8, 2002, Vol. III, page 557.

[21] Id., page 562. Nevertheless, sensitivity testing that compares modeled to modeled concentrations as inputs to models are varied is useful. For example, modeled sulfur dioxide concentrations linearly (almost) increase or decrease with an increase or decrease in a source's emissions.

[22] North Dakota's SO2 PSD Air Quality Modeling Report, section 3.4.

[23] No change has been made to input values for variable MDISP as set in the State's 2003 protocol. EPA Region 8 used the same input value for MDISP per Exhibit 8 from the department's May 2002 hearing docket (EPA's draft 2002 report), page 15, and Exhibit 84 (EPA's draft 2003 report), page 17.

[24] Section 2.4 in Exhibit 81 from the department's June 2003 hearing.

[25] Section 2.1.2 in Exhibit 8 from the department's May 2002 hearing.

[26] Section 3.1 in Exhibit 84 from the department's June 2003 hearing.

[27] EPA Region 8 could not complete an accuracy performance analysis, as recommended by EPA's guideline at Section 10.1.3 of Appendix W attached to 40 CFR Part 51, because it modeled an inventory

included a description of the State's 2002 accuracy performance test; [28] this test included hourly CEM sulfur dioxide emission rates for major sources rather than the Region's 90th percentile rates among other differences in inputs. [29] (See section 9.)

of increment affecting emissions rather than inventories of current and PSD baseline emissions.

[28] Section 2.2.2 in Exhibit 8 from the department's May 2002 hearing.

[29] The base time step for the CALMET and CALPUFF models is one hour. CEM stack monitoring of sulfur dioxide emission rates at power plants and some gas processing plants began about 1996. Hourly CEM sulfur dioxide emission rates for a source vary from hour to hour as input to CALPUFF. Actual emission rates (annual total emitted sulfur dioxide during operating hours as defined by rule) and 90th percentiles of hourly CEM rates, being constants, do not vary from hour to hour as input to CALPUFF.

Hourly CEM rates for a source are larger than the 90th percentile rate for that source 10 % of the hours throughout the year; but sums of those CEM rates for all sources for each hour exceed the sum of respective sources 90th percentile rates only 1.5% of the hours throughout the year. The sums of CEM emission rates for all sources for each hour exceed the sum of the respective source actual emission rates about 26 % of the hours throughout the year. (See Exhibit 33 from the department's May 2002 hearing.)

The numbers (26% and 1.5%) do not express the risk of exceeding a PSD increment, because the power plants are not co-located and because winds infrequently carry pollutants westward from the power plants. (See 900 millibar wind rose on page 21 in the report at Tab "B" of North Dakota's SO2 Air Quality Modeling Report and also Appendix B in the report at Tab "C".)

3. Unique aspects of the enhanced RUC2[30] weather data

Modeling, which used the enhanced RUC2 data, was first presented by ENSR Corporation on behalf of Basin Electric Power Cooperative during the department's May 2002 hearing. [31] Additional modeling with the data was presented to EPA Region 8 and the State by ENSR in March of 2003 [32] and at the department's June 2003 hearing. [33]

A. The enhanced RUC2 analytical weather data are a derivative of NOAA's Rapid Update Cycle version 2 (RUC-2) hourly prognostic data. The RUC-2 model provides data having a 40 kilometer horizontal resolution over each of 40 layers in the vertical dimension. The data are available for years 2000, 2001 and 2002. WindLogics, Inc., adapted the ARPS Data Assimilation System (ADAS) to assimilate hourly surface weather data and terrain data with the RUC-2 data and to extrapolate these data to a 10 kilometer horizontal resolution in a format compatible with the MM5 data ingest capability of CALMET. [34]

B. When modeling on the mesoscale, "[i]t is critical to get the meteorology right in order to assure that the model's puffs actually go in the right direction throughout their lifetime." [35] The enhanced RUC2 analytical data have features more advanced than the prognostic data provided by the PSU–NCAR MM5

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[30] The descriptor "enhanced RUC2" appears as "RUC2d" or as "RUC2^{d}" in other department reports.

[31] Exhibits 41 and 58 from the department's May 2002 hearing.

[32] "Revised CALPUFF Analysis with Year 2000 MM5 Meteorological Data: PSD Increment Consumption in Class I Areas in North Dakota and Eastern Montana," dated March 2003 by ENSR Corporation. This document is also Tab "B" of Volume 3, Exhibit 95, from the department's June 2003 hearing.

EPA Region 8 provided initial reactions (comments) in a letter by Richard R. Long, Director, Air and Radiation Program, dated May 14, 2003, to Terry O'Clair, North Dakota Department of Health. This letter is Tab "A" in Volume 6 of Exhibit 95 from the department's June 2003 hearing. In this letter, the Region claims that differences in sulfur dioxide emission rates, rather than meteorological data, are the reasons for the differences in the modeled concentrations of the Region and ENSR.

[33] Exhibits 73 and 95 from the department's June 2003 hearing.

[34] "RUC Analysis-based CALMET Meteorological Data for the State of North Dakota," dated August 24, 2004, by WindLogics, Inc., St. Paul MN. Page 5.

[35] Supplemental Written Testimony of Walter A. Lyons, which is Tab "D" in Volume 5 of Exhibit 95 from the department's June 2003 hearing. Page 9.

When using the enhanced RUC2 data, CALPUFF did advect puffs so as to often coincide with daily timing of observed concentrations at monitoring sites. (See Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report, section 4.1.)

prognostic meteorological data. [36] (See also section 7.1.) The technical advantages of the enhanced RUC2 data [37] are:

(1) The RUC2 model applies Four Dimensional Data Assimilation (FDDA) each hour, which controls and reduces error propagation. MM5 data is typically available at 3 or 6 hour intervals; and the MM5 model is nudged back to observations at similar intervals.

(2) The RUC2 model assimilates a variety of weather data from multiple sources, including hourly NWS surface observations and every twelfth hour upper air observations from NWS weather stations.

(3) The interpolation of RUC2 data from the 40 kilometer grid to the 10 kilometer grid uses the Bratseth method while reintroducing missed NWS surface observations with the ADAS software. CALMET completes the interpolation to the scale of its meteorological grid (DGRIDKM).

(4) Given (1), (2), and (3) above, the enhanced RUC2 data are results of analyses rather than prognostic forecasts [i.e., MM5] and are better suited for CALMET first-guess fields. [38]

(5) The CALMET interpolated NWS wind observations for the grid cell nearest wind towers are biased to speeds less than wind tower observations. CALMET interpolated RUC2d winds to that grid cell exhibit better agreement with wind tower observations, although also less than the wind tower observations. [39] No comparable analysis

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[36] The meteorological model (MM5) is supported by Penn State University (PSU) and the National Center for Atmospheric Research (NCAR). "To continue 'business as usual' with respect to meteorological data inputs (as still permitted in current EPA modeling guidance) for regional modeling is simply not supportable in light of recent advances." Supplemental Written Testimony of Walter A. Lyons, which is Tab "D" in Volume 5 of Exhibit 95 from the department's June 2003 hearing. Page 14. See also page 29.

In May 2003, EPA dismisses the quality and representativeness of the enhanced RUC2 data in favor of traditional observations from conventional sources. (See page 1 of a letter by Richard R. Long, Director, Air and Radiation Program, dated May 14, 2003, to Terry O'Clair, North Dakota Department of Health.) Later, the department arranged for a workshop briefing by WindLogics, Inc., that was held July 13, 2004, in St. Paul, MN. EPA attended this workshop.

[37] "RUC Analysis-based CALMET Meteorological Data for the State of North Dakota," dated August 24, 2004, by WindLogics, Inc., St. Paul MN.

[38] Id., page 5.

[39] "Comparison of CALMET Wind Speed Predictions With Measurements from Wind Energy Meteorological Towers in Western North Dakota," dated June 3002. Prepared by ENSR Corporation.

between wind tower observations in North Dakota and MM5 wind data has been reported. (See also section 7.1.)

(6) Apparently, EPA's contractor compared the MM5 data used by EPA in its 2003 modeling with NWS surface observations. The performance metric, which is a wind index of agreement, was about 0.7. [40] However, the enhanced RUC2 surface winds more closely agree with NWS surface winds. [41] (See also section 4.2.)

(7) The results in (5) and (6) above are examples of empirical confirmation of modeling techniques and data.

C. Some input values for CALMET control-file variables that are applicable when using only NWS data are inappropriate when using the enhanced RUC2 data due to differences in spatial and temporal scales of the NWS observational data and the enhanced RUC2 data. Those variables include DGRIDKM, NX, NY, IEXTRP, TERRAD, R1 and R2. (See sections 4.1.2 and 7.1.)

D. All input values for CALPUFF control-file variables, except DGRIDKM, grid domain variables and XSAMLEN, are the same whether using only NWS observations or using the enhanced RUC2 weather data. Input values for domain variables NX, NY, IBCOMP, JBCOMP, IECOMP, and JECOMP are set to maintain the size of model meteorological and computational domains. (See section 5.1.)

E. Neither the State nor the EPA had used the enhanced RUC2 data in respective 2002 or 2003 modeling protocols. The application of the enhanced RUC2 data in the MOU protocol apparently is the first use of the data in a CAA State Implementation Plan (SIP) action. [42]

This document is Tab "E" of Volume 3, Exhibit 95, from the department's June 2003 hearing. Pages 4-1 through 4-6. Note – this comparison study was completed prior to a WindLogics, Inc., discovery of a software error in interpolation of original RUC-2 data to the enhanced RUC2 10-kilometer grid.

This comparison is significant because the wind tower data were not assimilated with other data by the RUC-2 model.

[40] "Annual Application of MM5 to Support 1994 Calpuff Air Quality Modeling," dated 17 December 2002 by Alpine Geophysics, LLC, for US EPA Region 8. Pages 3-1 to 3-3.

[41] "A Comparison of NOAA RUC Analysis Surface Winds and ADAS-Enhanced RUC Analysis Winds with Surface Observations," dated August 27, 2004, by WindLogics, Inc., St. Paul MN. Pages 6–10. This document is also Tab "D" of North Dakota's SO2 PSD Air Quality Modeling Report.

[42] Personal communication with Dr. Dennis Moon, WindLogics, Inc. Fall 2003.

4. Upgraded CALMET inputs

Brief explanations of the functions of CALMET control-file input variables are provided in table 1a. Input values or settings for these variables are also shown in table 1a – as used in the State's 2003 protocol and in the MOU protocol. The "alternative NWS only" option in the table has not been executed.

4.1 EPA did not inquire or comment on the following CALMET input changes to the State's 2003 protocol in drafts of the MOU protocol.

4.1.1 When using only NWS observational data

A. Input variable ZFACE was changed to reflect stack heights of emitting sources and standard rawinsonde pressure altitudes. The changed values for ZFACE increased layering of wind fields from ground level to 500 meters, while retaining twelve layers (NZ). (There was no written explanation for previous ZFACE values.) The standard atmosphere 850 millibar pressure altitude is approximately 500 meters above ground at Bismarck, and rawinsonde wind data are obtained twice daily at this and other standard pressure altitudes.

B. Input variable BIAS is used by CALMET's Step 1 wind field calculations when vertically extrapolating NWS weather data. This variable was changed so that NWS surface wind observations are not blended with NWS upper air wind observations at altitudes of 500 meters (about 850 millibar) and higher above the ground surface.

C. The default value for CALPUFF input variable MCTADJ activates pollution plume path adjustments due to terrain; the default value, which is 3, was not changed. The default value for CALMET input variable ISLOPE activates slope air flows; the default value, which is 1, was not changed. The value for CALMET input variable TERRAD, which is a function of the dominant scale of terrain, was decreased to approximately three times the input value for DGRIDKM. The change should enhance local terrain influence on winds by increasing some calculated slopes and, thus, locally influencing puff or slug pathways.

D. Apparently, values for input variables R1 and R2 were the same in the State's 2003 protocol, as well as EPA's 2003 protocol, when using MM data blended with the NWS data as when using only NWS wind data. [43] These variables control radial distances for horizontal interpolation of NWS wind observations when re-introducing these data in Step 2 layered wind field calculations. (In retrospect, see section 7.1.2.)

[43] The State's 2003 protocol set the value for R1 as 40 kilometers and the value for R2 as 60 kilometers. EPA's protocol set the value for R1 as 1 kilometer and the value for R2 as 10 kilometers.

E. CALMET variable MNMDAV limits the upwind or back trajectory distance for averaging mixing heights and temperatures calculated for grid cells of the meteorological grid. However, post MOU-protocol examination of the CALMET code revealed that the code limits the maximum back trajectory to an air parcel travel distance during one time step, which is one hour (3,600 seconds). Travel distances during a time step increase or decrease as the wind speed increases or decreases. (In retrospect, see section 7.1.2.)

F. Input variable ILEVZI was changed from NZ level 4 to level 3. Wind vectors at this level are used by CALMET to determine the back trajectory travel distance during one time step. Although wind speeds at NZ level 1 are used to calculate mechanical mixing depths, wind speeds above NZ layer 1 are used by CALPUFF for advecting puffs or slugs. [44]

G. The department has assimilated 2001 and 2002 NWS observational data into files suitable for ingest by CALMET. When no MM input data are used, the observational data are used by the model for Step-1 initial guess wind fields and for Step-2 wind field calculations. [45] When MM input data, such as the enhanced RUC2 data, are used as the Step-1 initial guess wind field, the observational data are only used in Step-2 wind field calculations.

4.1.2 When using enhanced RUC2 data

A. Input variable DGRIDKM should relate to the scale of terrain features in the modeling domain, because the enhanced RUC2 data are much more spatially (i.e., horizontally and vertically) and temporally robust than NWS twice-daily upper air and hourly surface weather data. These terrain features include the Missouri River, the Yellowstone River, the Little Missouri River, Lake Sakakawea and Lake Oahe; the local air shed drainage for these features is often only 3 to 5 kilometers wide. So, the input value for DGRIDKM is set as 3 kilometers.

(1) Input values for NX and NY are set accordingly so as to sustain the size of the modeling domain.

B. The input value for TERRAD was set at 10 kilometers, which is about three times the value for DGRIDKM.

C. The grid scale for the enhanced RUC2 data is10 kilometers. So, the input values for R1 and R2 were set at 10 kilometers to preserve the advanced features of the enhanced RUC2 wind data. (See sections 3 and 7.1.)

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[44] "A User's Guide for the CALPUFF Dispersion Model," Version 5, dated January 2000 by Earth Tech, Inc., Concord, MA. Page 2-37.

[45] Id., sections 1.3 and 2.2.

4.2 The enhanced RUC2 data has not been used in CAA PSD modeling protocols. So, EPA recommended an additional written technical description of the enhanced RUC2 data [46] and a statistical comparison of RUC2 wind data with NWS surface wind data. These recommendations resulted in the following actions by the department.

A. The department contracted with WindLogics, Inc., (formerly SSESCO) for a paper that provides an additional description of the ADAS enhanced Rapid Update Cycle (RUC-2) data. [47]

B. WindLogics, Inc., was also contracted to compare enhanced RUC2 10-meter wind speeds with NWS 10-meter wind speeds. [48]

[46] A technical discussion of the enhanced RUC2 data was included as Attachment 2 to the MOU alternate modeling protocol. See Tab "B" of North Dakota's SO2 PSD Air Quality Modeling Report.

[47] "RUC Analysis-based CALMET Meteorological Data for the State of North Dakota," dated August 24, 2004, by WindLogics, Inc., St. Paul, MN.

[48] "A Comparison of NOAA RUC Analysis Surface Winds and ADAS-Enhanced RUC Analysis Winds with Surface Observations," dated August 27, 2004, by WindLogics, Inc., St. Paul, MN.

5. Upgraded CALPUFF inputs

Brief explanations of the functions of CALPUFF control-file input variables are provided in table 1b. Input values or settings for these variables are also shown in table 1b – as used in the State's 2003 protocol and in the MOU protocol. The "alternative NWS only" option in the table has not been executed.

5.1 EPA did not inquire or comment on the following CALPUFF input changes to the State's 2003 protocol in drafts of the MOU protocol.

A. The computational grid is a truncated meteorological grid on the south by 15 kilometers, on the north by 15 kilometers, and on the east by 30 kilometers where domain boundary induced interpolative constraints can occur. The truncation on the east also limits puff or slug travel distances in wind reversals that could exceed 300 kilometers before reaching a state PSD Class I area. The west end of the meteorological grid was not truncated due to major stationary sources located near there. The changes should decrease computer run time. Given the large modeling domain and the locations of sources in that domain, these changes should not affect model predicted concentrations.

B. Input variable MPDF was changed so that vertical dispersion under thermally induced convective conditions is calculated using a probability distribution function. The change is consistent with recommended use of the AERMOD model and with EPA's 2003 draft modeling report. [49]

C. Input variable XLAT has been changed so that it's at the south to north center of the TRNP Class I areas and sources to the east. The change, which also is consistent with the center of the modeling domain, could possibly reduce photochemical oxidation of sulfur dioxide during plume transport.

D. The largest observed ambient sulfur dioxide concentrations at sites of monitors occur throughout the year. [50] Input variable IVEG was changed to represent the condition of vegetation, on average, throughout the growing and dormant seasons. [51] For example, vegetation is dormant five or six months of the year in the geophysical setting of North Dakota. The change is consistent with EPA's 2003 draft modeling report, and it will not increase the impact of vegetation as a sink for sulfur dioxide during plume transport, but it could decrease the impact.

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[49] "A User's Guide for the CALPUFF Dispersion Model," Version 5, dated January 2000 by Earth Tech, Inc., Concord, MA. Page 2-40.

[50] Tab "B" of North Dakota's SO2 PSD Air Quality Modeling Report. Appendix H.

[51] When the model is executed for each season rather than for the year, an input value for IVEG can be set as appropriate for each season.

E. When using the enhanced RUC2 weather data, variable XSAMLEN was changed to match IWAQM's recommendation, since the value for DGRIDKM is 3 kilometers. When using only NWS observational data, XSAMLEN was set to 0.6, which is also 3 kilometers. [Note. Results of one sensitivity test suggests the input value should be 0.5 when the grid scale is 10 kilometers].

F. Input variable IRESPLIT was changed since seasonal nocturnal shear over North Dakota develops about 2 hours after sunset and persists until about sunrise. [52] Due to apparent CALPUFF programing, a consequence of this change is that there is no restriction during the calender day when pollutant puffs can be split vertically.

G. Vertical puff or slug splitting is also controlled by variable ROLDMAX. The input value for this variable was changed so as to increase the potential for vertical splitting and, thus, increase use of the NZ layered winds for puff or slug advection.

H. The x:y coordinates for each stack of all power plants (except the Beulah Power Plant), the refineries and the gasification plant have been included rather than one x:y set for the plant. Emitting units within industrial plants are separated by tens of meters or more, and in one instance by about one-half kilometer. See section 7.3.

I. Input variable SIGMAYI was changed to create an initial plume width at stack top that relates to stack diameter. [Note. CALPUFF re-sets SIGMAYI values that are less than 1 meter to 1 meter.]

5.2 Model receptors were added on the perimeters of the South and North Units of TRNP due to EPA comment on a draft of the MOU protocol, and input variable NREC was changed accordingly. The perimeter receptors were placed about two kilometers diagonally from receptors on the two-kilometer Cartesian grid.[53]

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[52] Per personal communication with a meteorologist employed at the Bismarck Office of the National Weather Service. Winter 2003-2004. (". . . the low level jet often does not start until after the evening balloon launch and has largely dissipated before the morning launch, . . ." See page 23 in Supplemental Written Testimony of Walter A. Lyons, which is Tab "D" in Volume 5 of Exhibit 95 from the department's June 2003 hearing.)

[53] See page 28 in the MOU protocol.

6. Upgraded SO2 emission rates

PSD baseline and current sulfur dioxide emission rates for power plants, refineries and other sources are shown in tables 2a, 3a and 3b as used by the department in 2003 and as provided by the MOU protocol. See also paragraph 7.2.1.A.

6.1 EPA did not inquire or comment on the following CALPUFF input changes to the State's 2003 protocol in drafts of the MOU protocol.

A. During a State and EPA meeting that spawned the MOU, the State committed to changing baseline coal sulfur content (percent by weight) of feed coal for coal-fired boilers. The average coal sulfur content for calculation of baseline emission rates now represents the coal that was used to fire boilers during the two consecutive years of baseline normal operations rather than the coal that was used from the mine source at the time of the PSD minor source baseline date until a later year when coal was obtained from another mine source (referred to as life of mine). These changes are consistent with July 2003 hearing findings by the State Health Officer [54] and reduce baseline emission rates of several coal-fired boilers. [55]

B. The following changes relate to an MOU provision (subpart I, paragraph 3) that baseline emission factors are to be consistent with other data sources.

(1) The baseline emission factor for the Beulah Power Plant was decreased so as to be consistent with the CEM based emission factor for Unit 1 of Heskett, because boilers at the Beulah plant were stoker fed as is Unit 1 of Heskett. The change reduces the plant's baseline emissions.

(2) The baseline emission factor for the Neal Station was increased from 30.0S to 32.9S, per source testing during the early 1970s. [56] S is the sulfur content of the coal fired in the station's boiler. The change increases the station's baseline emissions.

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[54] Section 10.1 of the September 8, 2003, Order of North Dakota State Health Officer Terry L. Dwelle.

[55] On an annual basis, these changes added nearly 11,000 tons of sulfur dioxide to the pool of PSD increment consuming emissions.

[56] The ash of North Dakota lignite coal has a sodium oxide content within the range of 2 to 8 percent. For example, see pages 24–25 in Exhibit 83 from the department's June 2003 hearing, which is titled "Prevention of Significant Deterioration – Sulfur Dioxide: Final Baseline Emission Rates," dated May 2003 and prepared by the department. In addition, sodium oxide data provided with annual source emissions inventory reports and unpublished data obtained from the Energy and Environmental Research Center, Grand Forks, North Dakota.

Thus, the average sulfur dioxide emission factor for boilers burning local lignite coal is 32.3S. Page 4-37 of Emission Factor Documentation for AP-42 Section 1.7, Lignite Combustion dated April 1993 and prepared for the US EPA Office of Air Quality Planning and Standards.

(3) The baseline emission factor for the M.R. Young Station Unit 1 was increased from 31.8S to 33.3S per source testing conducted during the early 1970s, because of uncertainty in calculated emission factors using current time coal and emissions data. [57] The change increases the unit's baseline emissions.

C. The two consecutive years that represent baseline normal operations have been changed to reflect boiler capacity utilization of all units at power plants, [58] due to EPA Region 8 remarks while negotiating the MOU. In effect, all emitting units at a plant are assigned the same two-year period for normal operations. As a consequence, the two-year period of normal operations for the Leland Olds Station Unit 1 and the M.R. Young Station Unit 2 changed from the two-year period in prior State protocols.

D. Current time (2000-01) sulfur dioxide emission rates from stacks for the Lignite Gas Plant and the Grasslands Gas Plant have been included, because these sources first began deep well injecting sour gas during 2002. The emissions of these sources are also needed for accuracy tests, which compare modeled concentrations to monitored concentrations.

E. Although EPA Region 8 did comment on the department's oil and gas production (flares and treaters) sulfur dioxide inventories in its 2003 draft modeling report,[59] it did not comment on these inventories during discussions on drafts of the MOU protocol.

6.2 EPA Region 8 indicated that amounts of alkaline constituents in coal ash or slag may have changed from PSD baseline to current time and, and if so, such change would have affected sulfur dioxide emissions. It requested a review of a report on coal data and stack testing conducted in the early 1970s. [60] The report's data for alkaline constituents were compared to a recent report's data ; the later data indicated no apparent significant differences in alkaline constituents.

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[57] A subsequent updating of coal sulfur content and CEM sulfur dioxide data resulted in a four year (2000-2003) average emission factor for sulfur dioxide of 32.3S. See table 2b.

[58] Data for the utilization of rated heat input for coal-fired boilers of power plants are provided on pages 38 and 39 of the MOU protocol, which is Tab "B" of North Dakota's SO2 PSD Air Quality Modeling Report. Data for five years (1978-1982) after the minor source baseline date (December 19, 1977) for sulfur dioxide are shown to illustrate utilization trends. Graphs of the utilization of rated heat input for additional years forward through the 1990s are shown in Exhibits 82 and 83 in the docket for the department's June 2003 hearing.

[59] Exhibit 84 from the department's June 2003 hearing, page 21.

[60] "Some Studies on Stack Emissions from Lignite-Fired Powerplants," by G.H. Gronhovd, P.H. Tufte and S.J. Selle published in "Proceedings: Bureau of Mines-University of North Dakota Symposium, Grand Forks, N.Dak., May 9-10, 1973." US DOI Information Circular 8650.

7. Recommended MOU protocol updates

7.1 Recommended input updates for CALMET and CALPUFF variables

The MOU protocol provides the input values for model control-file variables on pages 10–12 and 14–15. The department's Protocol Results Report concludes with the question "In retrospect, are there technically better choices for values or setting of some CALMET and CALPUFF control-file variables that would result in improved agreement between predicted sulfur dioxide concentrations and observed concentrations in western North Dakota?" [61] So, the input values or settings for several variables were re-examined. In addition, the modeled results of execution of the MOU protocol [62] and the surface and 900 millibar wind vector animations prepared by WindLogics, Inc., provide cause for assessing possible updates to input values for a few model control-file variables.

Lists of model variables and input values or settings for these variables, including recommended updates for input values or settings, are shown in tables 1a and 1b.

7.1.1 Advanced updates

A. The technical advantages of the enhanced RUC2 data, as described in section 3, [63] provide an opportunity to use that data as observations; for example, CALMET variable IPROG set as 15.

(1) But that approach has not been the norm in application of MM5 prognostic weather data. Normally, MM5 data are incorporated by CALMET as the initial guess wind field (Step 1). Per EPA's John Irwin, "reviewing agencies are not ready to accept" the enhanced RUC2 data as pseudo observations. [64]

(2) An alternative is to set values for variables R1 and R2 low so as to preserve the enhanced RUC2 wind data in Step 2 calculations. [65]

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[61] Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report, section 10.4.

[62] Id., section 9.0.

[63] When using the enhanced RUC2 data, CALPUFF did advect puffs so as to often coincide with day to day peaks of observed concentrations at monitoring sites. (See Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report, section 4.1.) Exceptions occurred during prolonged day to day periods of higher observed concentrations at the monitoring site in the South Unit of TRNP during 2000 and 2002. (Id., Appendices B and C.)

[64] "Revised CALPUFF Analysis with Year 2000 MM5 Meteorological Data: PSD Increment Consumption in Class I Areas in North Dakota and Eastern Montana," dated March 2003 by ENSR Corporation. Page 2-4.

[65] Id., pages 2-4 and 2-5.

B. More specifically, vertical extrapolation of the NWS observations to the CALMET grid and then horizontal blending the extrapolated wind data with the enhanced RUC2 can degrade the quality of the enhanced RUC2 data, given the large spatial separation of the observations. ". . . , the process of time-interpolating between widely spaced (in time) observations or fields, is by its nature, a smoothing of the data. Any directional turning has the effect of wind components canceling each other out in the interpolation, resulting in reduced wind speeds. . . . the integrity of the flow features is not preserved, and the blurred out representation of the features does not preserve the wind speeds." [66]

(1) The point above that time interpolation between widely spaced (in time) observations is a smoothing of those observations on the CALMET grid is illustrated with wind data collected at wind energy meteorological towers. [67] CALMET extrapolated and interpolated NWS wind observations to the grid cell nearest wind towers are biased to speeds less than wind tower observations. But, CALMET interpolated RUC2d winds to that grid cell exhibit better agreement, although are also biased to speeds less than the wind tower observations. [68]

(2) Therefore, a frequency distribution of modeled short-term sulfur dioxide concentrations using the enhanced RUC2 data would trend toward fewer of the larger concentrations when compared to a distribution using only NWS observations. When the lowest of wind speeds occur, sulfur dioxide emissions are the least diluted in air, which results in the highest modeled or observed sulfur dioxide concentrations. [69] Higher wind speeds provide larger volumes of air for dispersion of the emitted sulfur

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[66] "Comments on Upper Air Interpolation Shortcomings." Prepared by Dennis Moon of SSESCO (now WindLogics Inc.). This memorandum is attachment 6 to "Revised CALPUFF Analysis with Year 2000 MM5 Meteorological Data: PSD Increment Consumption in Class I Areas in North Dakota and Eastern Montana," dated March 2003 by ENSR Corporation.

[67] "Comparison of CALMET Wind Speed Predictions With Measurements from Wind Energy Meteorological Towers in Western North Dakota," dated June 2003 and prepared by ENSR Corporation. Note – this comparison study was completed prior to a WindLogics, Inc., discovery of a software error in interpolation of original RUC-2 data to the enhanced RUC2 10-kilometer grid.

[68] Id., pages 4-1 through 4-6.

[69] Errors in low wind speeds can significantly impact modeled concentrations. "The pollutant concentration in a puff moving at 1.5 miles per hour is 100% greater than one moving 3 mph." [See page 21 in Supplemental Written Testimony of Walter A. Lyons, which is Tab "D" in Volume 5 of Exhibit 95 from the department's June 2003 hearing.] Given the CAA PSD short-term sulfur dioxide increments, the modeled 2nd highest deterioration triggers an increment exceedance when that 2nd highest is larger than the increment – that is, the 2nd highest of 365 24-hour events or the 2nd highest of 2,920 3-hour events.

dioxide, which results in lower modeled or observed sulfur dioxide concentrations. [70]

(3) When variable IEXTRP is –4, the NWS wind observations, except calm winds (as ICALM is 0), are vertically extrapolated and blended in Step 2 with the enhanced RUC2 data. "In this approach, it must be assumed that surface winds are representative of the winds aloft during much of the day[;]" [71] for example, NWS upper air observations are obtained twice daily. The threshold between calm and non-calm winds is 0.0001 m/s as coded in CALMET. The advanced features of the enhanced RUC2 wind data are preserved when setting the value for IEXTRP to –1 rather than –4 (IWAQM's default), because observed surface wind speeds greater than 0.0001 m/s are not vertically extrapolated. [72]

(4) Given (1), (2) and (3) above, the setting for IEXTRP can possibly affect puff or slug pathways, dispersion and modeled concentrations. So, when using the enhanced RUC2 data, an updated input value for CALMET variable IEXTRP was set as –1.

C. The highest daily averages of sulfur dioxide at the site of the monitor in the South Unit of the TRNP and at other sites [73] included and/or were preceded by periods of low wind speed and calm winds. [74]

(1) Apparently, CALPUFF can produce simulated concentrations that are greater than plume model simulated concentrations during periods of calm winds (stagnant air) and wind reversals. [75] The apparent reason for this disparity is that ". . . [modeled] concentrations may become unrealistically large when wind speeds less than 1 m/s are input to the [model]" because the ". . . [steady-state Gaussian plume] model does not

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[70] Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report, page 45.

[71] Page 18 in Supplemental Written Testimony of Walter A. Lyons, which is Tab "D" in Volume 5 of Exhibit 95 from the department's June 2003 hearing.

[72] An input setting for variable IEXTRP of –1 had been used by ENSR Corporation. See Exhibit 58 from the department's May 2002 hearing.

[73] Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report, section 9.1.

[74] "Synoptic Analysis of Episodic Easterly Wind Events in Central-Western North Dakota for the Years 2000-2002," dated December 16, 2004, and prepared by WindLogics, Inc. In addition, accompanying wind vector animations for surface and 900 millibar levels during easterly wind events between August 22 and September 12, 2002.

[75] IWAQM's Phase 2 report, pages 6 and 17. The IWAQM report is Exhibit 29 in the docket for the department's May 2002 hearing.

apply during calm conditions, . . . Therefore, the [steady-state modeling] procedures disregard hours which are identified as calm." [76]

(2) In 1998, EPA concluded that "[The] complex interaction of transport, vertical mixing, and dispersion have an effect on concentrations with respect to downwind distances in CALPUFF. Occasionally, the accumulation of mass released over several hours will be transported in such a manner that the combined effect is to produce sharp localized maxima [[77]] in simulated concentration values. The occurrence of such events is not predictable. . . . Calm winds play a part in these events. These maxima seem to occur at most locations in the receptor network, at all downwind distances. [[78]] When they occur, they seem to affect in particular the results of the shorter averaging periods." [79]

(3) An example of the complex surface and 900 millibar wind regimes is illustrated with raw RUC2 data in figures 1a and 1b. Geophysical references for Class I areas and major source locations are south-north roadways 85 and 83 and west-east roadway I-94. Surface wind speeds are calm to light (about 3 m/s or less), [80] and surface air flows east to west from highway 83 to highway 85 where surface air flows south to north. Surface air in the area of I-94 also flows south to north. At the same time, air at 900 millibar generally flows south to north at 5 m/s (11.2 miles per hour) and higher.

(4) CALPUFF advects emitted pollutants by one of two methods – as circular puffs or slugs. [81] A slug represents the continuous emission of puffs each having infinitesimal mass. The length of the slug is

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[76] Section 9.3.4.1(a) of Appendix W attached to 40 CFR Part 51 (FR 68, page 18466).

[77] Because each 24-hour averaging period (calendar day) consists of 24 1-hour modeled concentrations, larger 1-hour sulfur dioxide modeled concentrations are averaged with lower 24-hour concentrations. Nevertheless, some ratios of modeled to observed concentrations were large. (See figure 6, table 6 and Appendix E in Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report.)

[78] The emissions inventories include flares and treaters within 10 kilometers of the state's PSD Class I areas, and major sources are located at greater distances from these areas. (See Tab "B" of North Dakota's SO2 PSD Air Quality Modeling Report, pages 18, 54 and 55.)

[79] "A comparison of CALPUFF with ISC3." Dated December 1998 by U.S. EPA, Office of Air Quality Planning and Standards, Research Triangle Park. Publication No. EPA-454/R-98-020. Page 20.

[80] Times of travel of emitted sulfur dioxide from stacks of power plants to PSD Class I areas can exceed 48 hours when wind speeds along travel pathways are 0.5 m/s (1.1 miles per hour) or less.

[81] "A User's Guide for the CALPUFF Dispersion Model," Version 5, dated January 2000 by Earth Tech, Inc., Concord, MA. Pages 2-7 – 2-22.

DGRIDKM, unless the model user specifies another length via variable XMXLEN. During calm periods (speeds less than 0.5 m/s), slugs are released as puffs and all emitted mass for the period (one hour) is placed into one puff. [82] The slug method is activated by setting CALPUFF variable MSLUG as 1. Slugs can be converted to puffs by variable SL2PF, which economizes computer run time. [83]

(5) When using non-steady state models such as CALPUFF, there is no procedure for disregarding calm winds as so done for steady-state models as quoted in paragraph (1) above. User's guides for CALMET and CALPUFF, which date to January 2000, do not discuss the calm wind issue in paragraph (2) above. CALPUFF input variable WSCALM sets the threshold between calm and non-calm wind speeds; the default value is 0.5 m/s (1.1 miles per hour). Wind speeds less than WSCALM are often set to the WSCALM value in the CALPUFF calculations. However, wind speeds less than 0.0001 m/s are treated as calm winds within the CALMET code; a user cannot change this value without recompiling the code.

(6) It is unclear whether occurrences of calm winds as illustrated in paragraph (3) above and the treatments of calm winds by the two models described in paragraphs (4) and (5) above are contributing to or causing the "sharp-localized maxima" in modeled concentrations per EPA's report quoted in paragraph (2) above. Therefore, the slug option will not be used; that is, MSLUG is set as 0 as shown in table 1.b.

7.1.2 Minor updates

A. When using only NWS observational data, the value for CALMET variable IEXTRP remains at –4 as in the MOU protocol, and an updated value for variable R1 was set to one-third the average distance (135 kilometers) between NWS surface stations in the modeling domain.

B. When using enhanced RUC2 wind data, updated values for R1 and R2 were set as one-half scale for the enhanced RUC2 data grid because of the good agreement between the enhanced RUC2 10-meter wind speeds and NWS surface wind speeds. [84] These changes reduce values for R1 and R2 from 10 to

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[82] Id., page 2-144.

[83] Id., page 2-20. The hybrid slug-to-puff approach is invoked by setting variable SL2PF, which is the ratio σ_y / (u dt), where u dt is the travel distance during time increment dt when the wind speed is u.

[84] "A Comparison of NOAA RUC Analysis Surface Winds and ADAS-Enhanced RUC Analysis Winds with Surface Observations," dated August 27, 2004, by WindLogics, Inc., St. Paul MN. Pages 6–10.

5 kilometers and limit the distance in Step 2 horizontal interpolation of winds in the wind layers so as to retain the enhanced RUC2 spatial variation of winds.

C. The input value for CALMET variable ZUPT was updated from the IWAQM default value of 200 meters to 270 meters to coordinate with ZFACE heights, since the heights of some source stacks are 201 and 210 meters.

D. Input values for CALMET variable MNMDAV were updated from values in the MOU protocol. The updated values were set to 7 grid cells (35 kilometers) when using NWS data only or to 12 grid cells (36 kilometers) when using the enhanced RUC2 data. Nevertheless, emitted pollution can travel distances in one hour that are longer than 35 kilometers when wind speeds are higher than 10 m/s (22.4 miles per hour). At higher wind speeds, grid cell to grid cell variation in mixing heights would likely be insignificant. (See paragraph 4.1.1.B.)

Recommended updated values for the variables in paragraphs A, B and D in section 7.1.2 are based upon a re-examination of technical considerations for these variables. Recommended updated values for variables in paragraphs C and E depart from the IWAQM values used in the MOU protocol for the reasons stated. A sensitivity test of updated values is described in section 9.

E. Vertical puff or slug splitting is also controlled by CALPUFF variables ZISPLIT and NSPLIT. The input value for ZISPLIT was updated from the IWAQM default value of 100 meters to 150 meters so as to increase the potential for vertical splitting. [85] The input value for NSPLIT was increased from 3 to 4 and, thus, increases use of the NZ layered winds given occasional vertical wind speed and direction shear above ground level as illustrated in figures 1a and 1b. [86]

7.2 Recommended updates for sulfur dioxide emission rates

Sulfur dioxide emissions rates are provided by the MOU protocol on pages 19 and 20. Sulfur dioxide emission factors and data for calculating PSD baseline emission rates are discussed in Appendices D and E of the MOU protocol and in section 6. Recommended updates to PSD baseline sulfur dioxide emission rates are included in table 3a. Recommended sulfur dioxide emission rates for 2002 and 2003 are shown in table 3b.

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[85] The nocturnal heights of the planetary boundary layer due to wind induced turbulent mixing would be useful forecast information, but are unknown. Per a personal communication with Rich Leblang, a meteorologist employed at the Bismarck Office of the National Weather Service. January 2005.

[86] The department contracted with WindLogics for a report that is titled "Synoptic Analysis of Episodic Easterly Wind Events in Central-Western North Dakota for the Years 2000 – 2002." The report is dated December 16, 2004. Also compare time concurrent surface and 900 millibar wind vectors from WindLogics' wind vector animations.

7.2.1 PSD baseline emissions

A. On further review of reported sulfur dioxide emissions data, the 2001 annual emissions inventory report by Great River Energy for Unit 1 of its Stanton plant should have indicated 9,424 tons rather than a flow-rate bias adjusted 9,046 tons as shown on page 47 of the MOU protocol, because EPA rules do not allow a downward adjustment of CEM emissions data when CEM flows are biased high. As a consequence, the CEM based AP-42 emission factor increased to 35.5S and the baseline emission rate for Unit 1 increased from 2,220.1 lb/op-hr to 2,271.3 lb/op-hr. [87] The corrected data are provided in tables 2a and 3a.

B. After April 2004, coal sulfur-content data and annual sulfur dioxide emissions from hourly CEM data were compiled for six un-scrubbed units of power plants for 2002 and 2003. These data are provided in table 2b.

(1) The data for the four years 2000 – 2003 are plotted in figure 2. Intuitively, emitted sulfur dioxide per ton of combusted coal should increase when the sulfur content of that coal increases, and vice versa. However, amounts of emitted sulfur dioxide also depend upon sodium oxide and, to a lesser degree, other oxide constituents in coal; [88] and, concentrations of oxide constituents in the state's lignite coal seams are highly variable.

(2) Table 2b also provides the 2000-2003 four year average sulfur dioxide emission factor for Heskett Units 1 and 2, GRE Stanton Unit 1 and M.R. Young Unit 1. The four year averaged emission factors vary at most 0.5 from the 2000-2001 two year emission factors that were used to calculate baseline sulfur dioxide emission rates. The additional coal and CEM data for these plants confirm the emissions factors used to calculate PSD baseline sulfur dioxide emissions as shown in table 2a.

(3) However, the 2000-2003 four-year averaged emission factor for Leland Olds Unit 1 increased to 39.2S from the 2000–2001 two-year average of 37.4S. The four-year average for Unit 2 is only 0.1S larger than the 2000-2001 average of 40.7S. The additional coal and CEM data for the two units of the Leland Olds power plant imply a bias for under

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[87] These corrections were implemented when executing the MOU protocol. See Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report, section 2.1.

[88] The alkali constituents in lignite are sodium, calcium and potassium in reactive form. Since potassium is generally present in very small amounts, the alkalies most responsible for sulfur dioxide retention in lignite fly ash are sodium and calcium. See "Some Studies on Stack Emission from Lignite-Fired Power Plants" by G.H. Gronhovd, et.al., dated May 1973 and presented at a Lignite Symposium in Grand Forks, North Dakota, page 6.

reporting coal sulfur content, because CEM system operations are within an acceptable performance tolerance. [89]

(4) Assuming that a bias for under reporting coal sulfur content occurred during PSD baseline years as well as during current years, emission factors of 39.2S and 40.8S, respectively for Units 1 and 2 of the Leland Olds plant, would be applicable in calculating PSD baseline emissions for these units. Using PSD baseline coal data, [90] the PSD baseline sulfur dioxide emission rate for Unit 1 becomes 3,783.5 lb/op-hr, and the rate for Unit 2 becomes 7,709.1 lb/op-hr.

7.2.2 Current emissions

A. Sulfur dioxide emissions data for 2000 and 2001 were used in the State's 2002 and 2003 modeling protocols and in the MOU protocol. Since then, annual and actual emissions have been compiled from hourly CEM sulfur dioxide emissions data for major sources for 2002 and 2003. The emissions data are included in tables 2b and 3b.

B. Annual rates as pounds per operating hour computed from hourly CEM emissions are shown for each year from 2000 to 2003 in table 3b. But, 2000-2001 and 2002-2003 rates as actual emissions for Unit 2 of the Leland Olds plant in this table are downward adjusted to the emissions factor of 38.7S from table 2a, which is consistent with the MOU protocol [91] and assumes some bias in hourly CEM data and in the sulfur content of coal. Similarly, the 2002-2003 rate as actual emissions for Unit 1 is downward adjusted to the emissions factor of 37.4S from table 2a, because emissions factors for 2002 and 2003 in table 2b are larger than 40S. This approach was used due to an imbalance between data for sulfur in feed coal and data for sulfur dioxide emitted from stacks.

C. However, when assuming CEM systems are operating within acceptable tolerances, the rate as actual emissions for Leland Olds Unit 2 for 2000-2001 as a weighted average of annual rates for 2000 and 2001 would be 8,566.0 lb/op-

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[89] For example, a "Continuous Emissions Monitoring System Relative Accuracy Determination" performed for Basin Electric Power Cooperative at Units 1 and 2 of the Leland Olds Station on April 3-5, 2002 and on September 24-26, 2002.

See also FR 58, pages 3727 to 3737, which indicates that the relative accuracy of the CEM system must be no greater than 7.5% of the mean value for the reference test data for sulfur dioxide.

In addition, system flow measurements were biased high by an amount greater than 3% for 2001; no bias correction was applied by the operator, because federal rules do not allow downward adjustment of CEM emissions data.

[90] The baseline coal data are provided in Appendix D of the MOU protocol, which is Tab "B" of North Dakota's SO2 Air Quality Modeling Report.

[91] Appendix E of the MOU protocol.

hr. Similarly, the rate as actual emissions for Leland Olds Unit 1 for 2002-2003 as a weighed average of annual rates for 2002 and 2003 would be 4,205.2 lb/op-hr, and the rate for Unit 2 would be 7,786.9 lb/op-hr.

7.3 Recommended source stack locations and stack parameters

Within days of providing EPA with the MOU protocol, the department noticed some errors in source stack locations and stack operating data. [92] Corrected source location and operating data are shown in tables 4a and 4b.

Since PSD baseline and current inventories of emitted sulfur dioxide are modeled separately, any changes after PSD baseline in stacks and stack operating data can be incorporated as source input data. One such change occurred for the stack at the Tioga Gas Plant.

Since execution of the MOU protocol, the department issued a construction permit to Red Trail Energy for an ethanol plant near Richardton, North Dakota. Stack location and operating data for this source are shown in table 4b.

7.4 Recommended updates to versions of CALMET and CALPUFF

The department has been using CALMET version 5.2 and CALPUFF version 5.4 as specified in the MOU protocol. Since 2000, the CALMET and CALPUFF models have been advanced to versions 5.5 and 5.7, respectively. The updated model executable codes can be downloaded from the Earth Tech web site. [93]

CALMET version 5.5 includes control-file variable ITPROG. This variable is not included in version 5.2, nor is it included in the user's guide for CALMET. The default setting of 0 for ITPROG directs use of temperature data from NWS observations. A setting of 2 redirects use of temperature data from MM5 data or from the enhanced RUC2 data.

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[92] "Revisions to pages 39 and 40 in the proposed alternative air quality modeling protocol dated April 30, 2004." This document is included under Tab "B" of North Dakota's SO2 Air Quality Modeling Report.
Corrected source coordinates were used when executing the MOU protocol. See section 2.1 in the Protocol Results Report, which is Tab "C" of North Dakota's SO2 Air Quality Modeling Report.

[93] http://www.calgrid.net/ The CALMET 5.5 and CALPUFF 5.7 downloadable versions have been available since an updated 40 CFR Part 51, Appendix W, was announced by EPA on April 15, 2003.

8. Tabulation of modeled concentrations

The State's 2003 protocol included averaging the modeled sulfur dioxide concentrations at model receptors in each Class I area for each hour and then computing 3-hour and 24-hour block averaged concentrations. The area receptor averages were used by that protocol to determine deterioration and compliance with PSD 3-hour and 24-hour increments.

The MOU protocol does not include receptor network averaging in Class I areas. Instead, deterioration (and improvement) in modeled concentrations is calculated for each receptor. This change from the State's 2003 protocol is consistent with July 2003 hearing findings by the State Health Officer. [94]

As provided by paragraph I.5 of the State & EPA MOU, modeled concentrations from current and PSD baseline inventories of emitted sulfur dioxide can be used for the paired-in-space-only method for tracking deterioration. Modeling of the current inventory also facilitates comparison of modeled concentrations to monitored concentrations. Modeling of both inventories also facilitates EPA's paired-in-space-and-time method for tabulation of changes in concentrations. Modeling of an inventory of increment affecting emissions, rather than both inventories, as used in EPA's 2002 and 2003 protocols does not facilitate the paired-in-space-only method.

[94] Section 10.1 of the September 8, 2003, Order of North Dakota State Health Officer Terry L. Dwelle.

9. CALPUFF results accuracy tests

"The analyst is responsible for recognizing and quantifying limitations in the accuracy, precision and sensitivity of the [modeling] procedure. . . . Both space/time pairing of [modeled] estimates and measurements and unpaired comparisons are recommended. Emphasis should be on the highest concentrations and the averaging times of the standards or increments of concern." [95]

Model accuracy performance tests compare sums of model predicted concentrations due to current time emissions and the background concentration (a constant) to actual observations of concentrations. The State's accuracy tests, as performed in conjunction with its 2002 and 2003 protocols, used: (A) only year 2000 observations at monitoring sites, (B) year 2000 CEM hourly sulfur dioxide emission of major sources, (C) a background concentration for modeled concentrations of 0 ug/m3, and (D) the 50 highest modeled concentrations during the year paired with the 50 highest observed concentrations during the year. [96]

The accuracy test was improved as follows. The background concentration for sulfur dioxide has been estimated using available monitoring data and set at 1.5 ug/m3, due to EPA comment on drafts of the MOU protocol. In addition, actual emissions of sulfur dioxide were used as specified in the MOU protocol, because the protocol results are being used to assess attainment of the PSD short-term sulfur dioxide increments. [97] Finally, the 25 highest modeled and observed sulfur dioxide concentrations during the year were used, since additional 24-hour averaged observations in PSD Class I areas approach the lower detection level of monitoring instruments.

When an accuracy ratio for 24-hour concentrations is tight, such as about 1.1, the highest predicted current-time concentrations are about 0.9 ug/m3 larger than the highest monitored concentrations. [98] For example, the annual second-highest 24-hour actual concentrations at the

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[95] Section 10.1.3(b) in Attachment W to 40 CFR Part 51 (FR 68, Page 18467). See also Section 10.2 of the Protocol Results Report, which presents an accuracy analysis paired place/time with monitoring data as well as an analysis paired only at place (site of the monitor).

[96] Exhibit 6 from the department's May 2002 hearing, which is titled "Calpuff Analysis Using Actual Annual Average SO2 Emission Rates (Draft);" and Exhibit 81 from the department's June 2003 hearing, which is titled "Calpuff Analysis of Current PSD Class I Increment Consumption in North Dakota and Eastern Montana Using Actual Annual Average SO2 Emission Rates."

[97] ". . . , it is desirable to quantify the accuracy or uncertainty associated with concentration estimates used in decision-making." Section 1.1.3(a) of Appendix W attached to 40 CFR Part 51 (FR 68, page 18467).

[98] An average of the 25 ratios of 1.00 is not a bright line between under and over prediction of modeled concentrations. For example, the largest 24-hour observations, which are averages of 24 1-hour observations, include hours when observed concentrations are less that the instrument's lower detection level. A taking of the accuracy math to days during the year when modeled concentrations are 0 ug/m3 and when observed concentrations are less than the monitoring instrument's lower detection level of

monitoring site in the South Unit of the TRNP during years 2000 through 2002 were around 9 ug/m3.

The department completed two additional model accuracy tests. [99]

(A) For the first test:

(1) CALMET version 5.2 and CALPUFF version 5.4 were used.

(2) Modified input values for CALMET control-file variables R1, R2, ZUPT and MNMDAV were used. For example, R1 and R2 were set to 5 kilometers and ZUPT was set to 270 meters. The input value for variable IEXTRP remained as –4; the updated input value of –1 for this variable was not used. Lastly, year 2002 enhanced RUC2 data were used.

(3) Modified input values for CALPUFF control-file variables MSLUG, SL2PF, ZISPLIT and NSPLIT were also used. For example, MSLUG was set to 1, ZISPLIT to 150 meters, and NSPLIT to 4. Finally, year 2002 sulfur dioxide emission rates were used as shown in table 3b. [100]

(4) The results of this accuracy test for the South Unit of TRNP are shown in table 5. The averaged ratios for the 25 highest 24-hour concentrations at the four monitoring sites did not deviate by more than 0.05 from prior results; [101] no other documentation of this test was prepared. [102] So, model predicted sulfur dioxide concentrations are not critically sensitive to the input values for these CALMET and CALPUFF variables. [103]

(B) For the second test,

(1) CALMET version 5.5 and CALPUFF version 5.7 were used.

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1 ppb (2.62 ug/m3) results in a ratio of 1.145 (1.50 divided by ½ of 2.62).

[99] The tests were completed by Steve Weber, a meteorologist on the department's staff.

[100] See also Tab "C" of North Dakota's SO2 PSD Air Quality Modeling Report, page 28.

[101] Id., page 25.

[102] Note that the ratios of predicted and monitored 24-hour concentrations (P/O) at this monitoring site get progressively larger toward the highest predicted and monitored concentrations. This P/O trend does not occur at the other sites.

[103] Id., §§ 1.5 and 10.4.

(2) All other model inputs were as specified by the MOU protocol, except year 2002 enhanced RUC2 data and sulfur dioxide emissions were used.

(3) The results of this accuracy test for the South Unit of TRNP are also shown in table 5. The averaged ratios for the 25 highest 24-hour concentrations at the four monitoring sites did not deviate by more than 0.02 from prior results; no other documentation of this test was prepared.

10. Another method for calculating air quality deterioration

The federal CAA, EPA rules and State rules allow one exceedance per year of the 3-hour and 24-hour PSD Class I sulfur dioxide increments. [104] An exceedance occurs when modeled deterioration is larger than the applicable increment. Deterioration is the change in modeled concentrations between PSD baseline and current time. Bias due to uncertainties in model algorithms and input data passes forward into modeled concentrations and calculated deterioration. [105]

There are no observed (actual) sulfur dioxide concentrations surrounding the PSD baseline time line for the State's PSD Class I areas. [106] And, meteorological data for the PSD baseline time line is not available. This data that would represent the weather that carried sulfur dioxide emitted by PSD baseline sources into the Class I areas. So, the MOU protocol uses air quality models to estimate concentrations at the PSD baseline time line due to the PSD baseline sulfur dioxide emitted by PSD baseline sources using three years of current time line meteorological data. [107] The protocol uses the same models and three years of meteorological data to estimate current concentrations due to current sulfur dioxide emissions. One set of enhanced RUC2 data are used for each year.

If data for observed sulfur dioxide concentrations were available for the PSD baseline time line as well as for the current time line, analysis of trends in concentrations between the two time lines would not follow EPA's method of pairing modeled concentrations at receptors in space and time for tracking PSD increment consumption [108] – because the meteorology that transports and disperses emitted sulfur dioxide is not the same day to day throughout the year during both time lines.

The MOU protocol's Alternate method for tracking PSD increment consumption establishes a sulfur dioxide baseline concentration (as defined by rule) at each receptor. [109] The baseline concentration is the second highest concentration during the year and is established with the modeled concentrations from modeling PSD baseline sulfur dioxide emissions. This method does not presume that day-to-day meteorology throughout baseline years and current years is the same.

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[104] For example, NDAC § 33-15-15-01(4.j).

[105] Appendix B of the MOU protocol and section 4 of the Protocol Results Report.

[106] Exhibits 20 and 21 from the docket for the department's May 2002 hearing.

[107] In addition, current time line land use/cover data, hourly ozone data and hourly precipitation data are used when modeling the baseline inventory, as well as the current inventory of emitted sulfur dioxide.

[108] EPA's method of time pairing modeled concentrations at model receptors is described at pages 25-28 of the MOU protocol.

[109] This method is also described at pages 25-28 of the MOU protocol.

If the federal CAA and rules did not prescribe the PSD sulfur dioxide increments, deterioration of 3-hour and 24-hour sulfur dioxide concentrations in Class I areas might be calculated with CALPUFF output data from execution of the MOU protocol as illustrated below.

Cumulative totals of modeled concentrations for each hour of the year – when using current sulfur dioxide emissions, including sources that have FLM certifications of no adverse impact – are block averaged for each day throughout the year. The 365 24-hour averaged concentrations are rank sorted highest to lowest, which to this point is the same procedure as used for model accuracy tests. Similarly, 365 daily averages of modeled concentrations when using PSD baseline sulfur dioxide emissions are computed and rank sorted. A background sulfur dioxide concentration of 1.5 ug/m3 has been added to each daily average of modeled concentrations, and the 25 highest are shown in table 6.

Observed sulfur dioxide concentrations are available for each year of the three annual enhanced RUC2 data sets. Daily averages of observed hourly concentrations are also calculated and rank sorted. The 25 highest are also shown in table 6, which to this point is also the same procedure as used for model accuracy tests.

The statistical mean of observed and modeled 24-hour concentrations can be determined –

(1) After omitting the highest average (rank of 1) as an outlier following general analytical practice for analysis of observed concentrations, and

(2) After omitting the lowest six averages among the 25 24-hour averages of observed concentrations. These six are more likely to include hours when actual concentrations were less than the lower detection level of monitoring instruments. [110]

The remaining eighteen 24-hour observed and modeled concentrations comprise 5% of the 365 days of the year.

The table at right shows the eighteen-day mean of observed (actual) 24-hour sulfur dioxide (SO2) concentration data at the site of the monitor in the South Unit of TRNP from table 6. The table at right also shows the total sulfur dioxide emissions from table 3b. The annual totals of sulfur dioxide emissions do not include oil field flare and treater emissions. [111] The total emissions decrease from 2000

Year	Total SO2 Emissions lb/op-hr	Mean SO2 Concentration ug/m3
2000	44,098.2	5.64
2001	43,624.4	5.92
2002	38,695.4	6.22

[110] Appendix H of the MOU protocol.

[111] Maps of flares and treaters within 50 kilometers of the South Unit and a table of amounts of emitted sulfur dioxide during PSD baseline and year 2000 are shown in Appendix F of the MOU protocol. The 2000 inventory was used when modeling 2001 and 2002 meteorology. An inventory of sulfur dioxide emitted by flares and treaters was not assembled for 2001 and 2002.

to 2002, but the mean of the observed sulfur dioxide concentrations increases. Clearly, annual differences in transport and dispersion meteorology, as well as annual amounts of emitted sulfur dioxide, affect concentrations of sulfur dioxide in the South Unit.

Data in table 6 illustrate the following:

(1) The average bias in the 18 modeled 24-hour concentrations when using current actual emissions is: for 2000 – +25% (7.07/5.64 - 1.0), 2001 – -5%, and 2002 – +41%. [112]

(2) The change in sulfur dioxide from the PSD baseline to current time comes from a ratio of respective means for the 18 modeled 24-hour concentrations. The changes are: for 2000 – +7% (7.01/6.59 - 1.0), 2001 – +5%, and 2002 – +12%.

(3) The bias in modeled 24-hour concentrations for 2000 and 2002 is larger than the increases in 24-hour concentrations occurring from PSD baseline to current time.

(4) The modeled 24-hour baseline concentration for 2000 is 8.68 ug/m3. The number of days of modeled concentrations that exceeded the baseline concentration are: for 2000 – 6, 2001 – 2, and 2002 – 2.

(5) Some of the same-rank highest modeled concentrations when using the PSD baseline emissions inventory are larger than concentrations when using the current emissions inventory – especially for 2000 and 2001. This outcome is likely due to differences in locations and emissions of major and minor sources between the two time lines and to differences in year-to-year meteorology.

One statistical null hypotheses is that the mean of the 18 24-hour sulfur dioxide observations is not different than the mean of the 18 modeled concentrations when using current sulfur dioxide emissions. If the probability for a greater difference between the two means is small (i.e., less than 10 percent), the null hypothesis is rejected and the difference is a measure of bias in the modeled concentrations.

Another null hypothesis is that the mean of the 18 modeled concentrations when using current sulfur dioxide emissions is not different than the mean of the 18 modeled concentrations when using PSD baseline sulfur dioxide emissions. If the probability for a greater difference between the two means is small (i.e., less than 10 percent), the null hypothesis is rejected and the difference is a measure of the deterioration occurring between the PSD baseline time line and the current time line.

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[112] See also table 6 in Tab "C" of North Dakota's SO2 Air Quality Modeling Report. The average of ratios using the accuracy test method of the MOU protocol were 1.20, 0.94 and 1.41, respectively, for 2000, 2001 and 2002.

Statistical tests have not been applied to the observed and modeled concentrations in table 6 so as to verify or reject each null hypothesis. Similar tables of data can be constructed for all receptors in the Class I area even though sulfur dioxide monitors are not located at each of these receptors.

Tables of data similar to table 6 for monitoring sites near Dunn Center and Hannover would likely show larger differences between modeled sulfur dioxide concentrations using the current and PSD baseline inventories, since (a) these sites are closer to major sources in central North Dakota where the observed concentrations are larger, [113] and (b) there are no offsetting emission reductions from nearby oil field flares and treaters. [114]

Data from table 8 in the MOU Protocol Results Report are shown in the table below, and data from table 6 are also shown in this table. Calculated deterioration using the same protocol output varies among the three methods shown. The paired-in-space-and-time method conceptually protects clean air days at PSD baseline from degrading beyond PSD increments, the paired-in-space-only method protects the worst concentrations from degrading "over the baseline concentration" beyond the increments (see paragraph I.5 of the MOU), and the 18-day mean method mimics a likely analysis of observed concentrations, if monitoring data were available during the baseline time line.

Deterioration using modeled 24-hour sulfur dioxide concentrations (ug/m3) for the South Unit of TRNP. *

Meteorological data	2000 [3]	2001 [3]	2002 [4]
Per CAA PSD – increment is 5 ug/m3			
H2H [1] EPA's paired in space and time	4.4	4.0	4.7
H2H Paired in space only	2.8	1.8	4.9 [5]
Paired in space only – at site of monitor [2]	0.8	1.9	2.2
Per difference in 18-day mean			
Not HSH – at site of monitor	0.5	0.3	0.9

* Data are derived from modeled concentrations using CALMET version 5.2 and CALPUFF version 5.4.

[1] HSH = high second high among all receptors

[2] Receptors at sites of monitors were not included in tabulation of HSH deterioration. (See Appendix H in the MOU protocol.)

[3] For 2000 and 2001, numbers are based upon 2000-2001 actual emissions.

[4] For 2002, numbers are based upon 2002-2003 actual emissions.

[5] See sections 7.2 and 9 of the MOU Protocol Results Report.

[113] For example, see Appendix H of the MOU protocol.

[114] See table and figures in Appendix F of the MOU protocol.

11. Comments

11.1 Regarding sections 4, 5, 7.1.2 and 9

There are three time-line clusters of major sources: those that were operating at baseline but later were retired (such as the Neal Station); those that were operating at baseline and also are operating at current time (such as the Leland Olds Station); and those that were placed into operation after the PSD trigger date or after the PSD minor source baseline date (such as the Antelope Valley Station).

Each CALMET and CALPUFF input change, except source emission rates, affects concentrations either as increases during both baseline and current time lines or as decreases during both time lines. The recommended updates to inputs for some model variables has minor effect on modeled concentrations.

11.2 Regarding sections 6, 7.2 and 7.3

Because some baseline sources ceased operations prior to the current time, because emissions of stationary sources operating at current time are different than emissions of these sources at baseline and because locations of sources during the two time lines differ, increases in concentrations during current time will not be offset by increases in concentrations during baseline. Similarly, decreases will not be offset.

The time period for a current emissions inventory is the two consecutive years preceding the date of concern, which coincides with an air quality control permit application or a periodic review for attainment of National Ambient Air Quality Standards or PSD increments. The inventory of current sulfur dioxide emissions will likely need updating so as to include 2004.

11.3 Regarding sections 3, 7.1.1 and 10

Meteorology is a critical component of modeling. The meteorological data used for modeling has improved in the form of the enhanced RUC2 data. Major sources in western North Dakota are widely separated and located more than 50 kilometers from PSD Class I areas. Place and time variant meteorology across the modeling domain dominates modeling outcome. Time pathways of emitted sulfur dioxide exceed 24 hours, especially when wind speeds are low which results in the highest observed concentrations in these areas. [115]

Modeled concentrations reflect these circumstances, and that outcome is likely due to the improved meteorological data. However, error or uncertainty in low wind speeds and corresponding wind reversals can cause significant error in modeled concentrations. In retrospect, section 10.4 in the MOU Protocol Results Report should reflect section 7.1 of this document.

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[115] See results of accuracy tests of modeled concentrations using actual emissions and hourly CEM emissions in section 6 of report at Tab "C" of North Dakota's SO2 Air Quality Modeling Report.

Correspondence between modeled and observed concentrations improves when same year emissions and meteorological data are used. The improved correspondence was illustrated when modeling 2002 sulfur dioxide emissions, rather than 2000-2001 actual emissions, with 2002 enhanced RUC2 in the MOU Protocol Results Report. The enhanced RUC2 data will be needed for 2003 and 2004 as sulfur dioxide emissions inventories are updated.

11.4 Regarding sections 9 and 10

The model accuracy test results in sections 9 and 10 of this report (and in the sections 6 and 10 of MOU Protocol Results Report) are based upon one monitoring site in the South Unit of TRNP. The methods for model accuracy analysis used in these sections would also apply to additional data from additional monitoring sites, if there had been additional sites of sulfur dioxide monitors in this area. Such additional data would not change the accuracy ratios for the existing South Unit monitoring site that are results of these accuracy analyses.

11.5 Tracking deterioration

Section 10.2 of the MOU Protocol Results Report confirms EPA's statement that ". . . models are reasonably reliable in estimating the magnitude of highest concentration occurring sometime, somewhere within an area . . . However, estimates of concentrations that occur at a specific time and site are poorly correlated with actual observed concentrations . . ." [116] The poor correlation occurs because the models do not adequately duplicate actual puff or slug pathways between sources and monitors.

If observed sulfur dioxide concentrations and meteorological data were available during PSD baseline years, results of a similar paired in space and time analysis comparing modeled concentrations using PSD baseline emissions and meteorology with the observed concentrations would also confirm EPA's statement.

EPA has preferred to model increment-affecting emissions to track deterioration. [117] This technique inherently time pairs modeled PSD baseline and current sulfur dioxide concentrations at each receptor, because model output represents deterioration (or improvement) in concentrations. The MOU protocol mimics EPA's methods by modeling PSD baseline and current inventories of emitted sulfur dioxide and then subtracting concentrations at baseline from time paired current concentrations at each receptor. [118] Deterioration that is enumerated by either method is scientifically credible only when there are no changes in locations of sources following baseline. It is not credible when there are

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[116] Paragraph b, section 10.1.2 of Appendix W attached to 40 CFR 51.

[117] An increment-affecting emission is the difference between a source's current and its baseline emissions.

[118] A difference may occur when puff or slug depletion algorithms are not linear functions of amounts of sulfur dioxide within the puffs or slugs.

changes in locations, because the models do not adequately duplicate puff or slug pathways between sources and monitors.

Finally, section 10 of this document illustrates that various analyses of observed and modeled sulfur dioxide concentrations are possible. These analyses are needed for a complete numeric description of concentrations and deterioration.

11.6 Summary

The process of improving the application of the CALMET and CALPUFF models began during 2000 following correspondence from EPA Region 8 in February of that year. [119] Since then, significant advancement of modeling to estimate the condition of sulfur dioxide concentrations in the state's PSD Class I areas has occurred.

This paper describes improvements to the State's 2003 protocol in an MOU process meant to achieve concurrence by EPA on a protocol suitable for SIP administration. This paper serves as a benchmark reference for future protocol enhancements.

Each additional modeling protocol since 2002 has expanded information on model sensitivity and accuracy performance and often corrected perceptions on the behavior of modeled concentrations. [120] (For example, see sections 1 and 10.) This progressive learning is enhanced, in part, with the modeling of both the PSD baseline and current sulfur dioxide emissions inventories.

This paper also recommends enhancements or updates for a few model inputs. These updates are the result of further examination of model users guides and model codes, as well as an additional WindLogics' report with wind vector animations and additional sulfur dioxide emissions data that were prepared or assembled subsequent to the MOU protocol.

Modeling involves numerous details, and it involves future exploration of the robust character of the models through additional sensitivity testing and accuracy testing as model science and model input data improve. These tests inform modelers of (1) the stability of model output when improving inputs that adhere to best available science as well as (2) the agreement between modeled concentrations and actual ambient concentrations.

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[119] Letter by Richard R. Long dated Feb. 1, 2000, in Exhibit 17. See also Section 7.0 of the September 8, 2003, Order of North Dakota State Health Officer Terry L. Dwelle. This order is Tab "E" of North Dakota's SO2 PSD Air Quality Modeling Report.

[120] Sensitivity tests compare modeled outcome against modeled outcome when changing model inputs or model algorithms. Accuracy tests compare model outcome to actual observations.

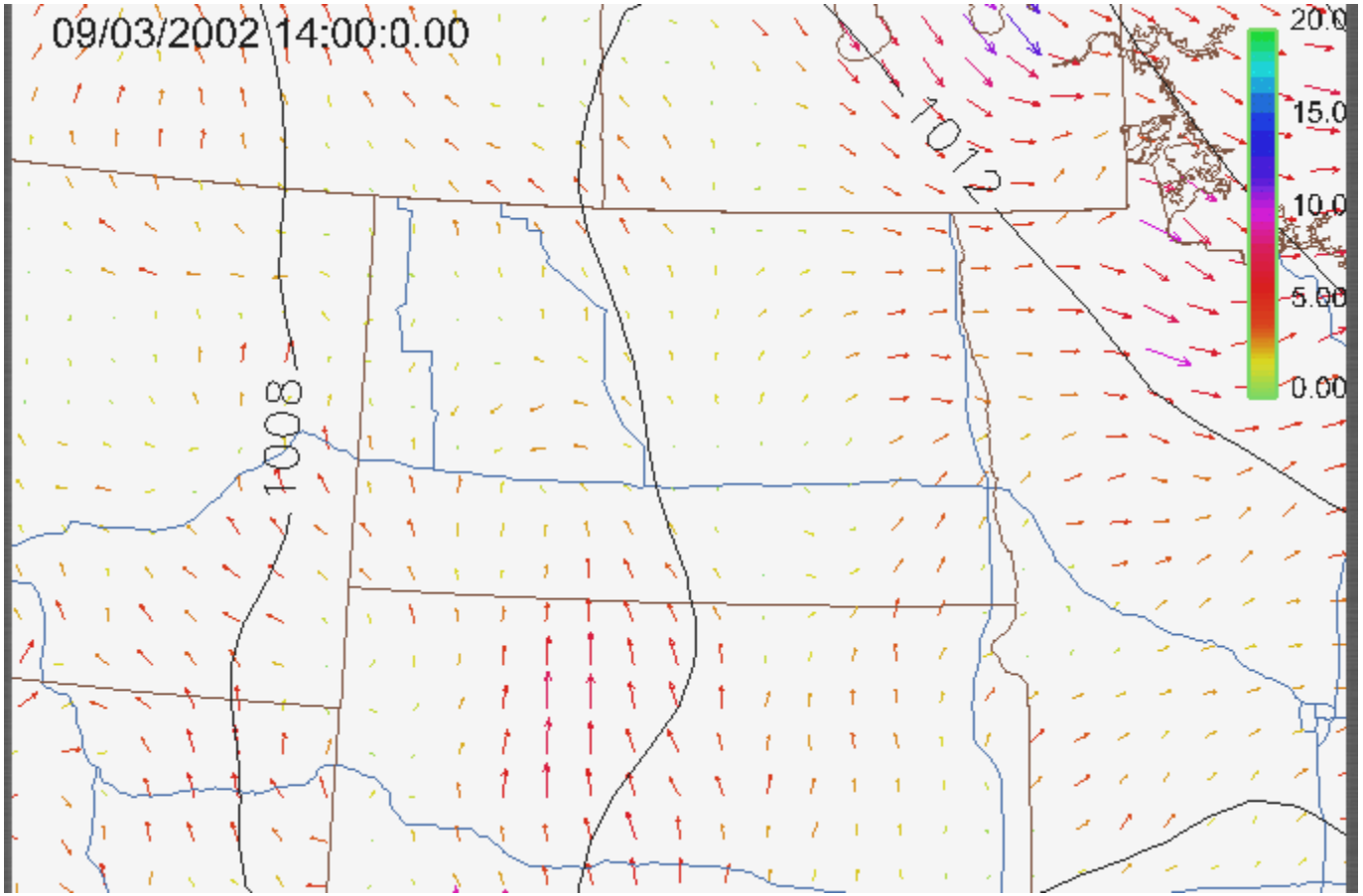

Figure 1a. Surface pressure isobars (mb) and vector winds from raw RUC2 (40 km grid) data at 1400 UTC on 3 September 2002. Color bar at upper right shows vector wind magnitude in m/s. The figure was taken from a surface vector wind animation prepared by WindLogics Inc.

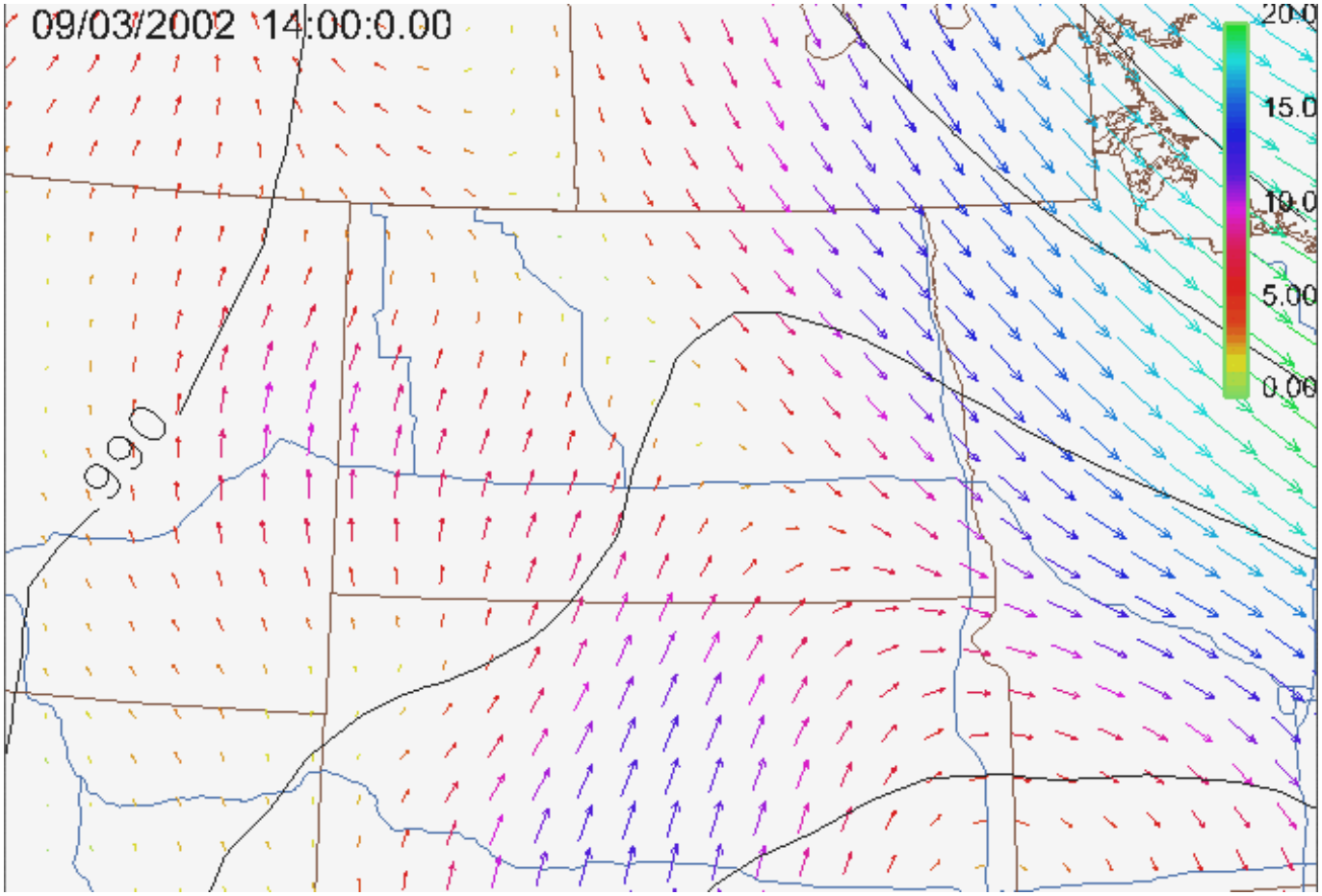

Figure 1b. Geopotential height isopleths (m) and 900 mb vector winds from raw RUC2 (40 km grid) data at 1400 UTC on 3 September 2002. Color bar at upper right shows vector wind magnitude in m/s. The figure was taken from a 900 mb vector wind animation prepared by WindLogics Inc.

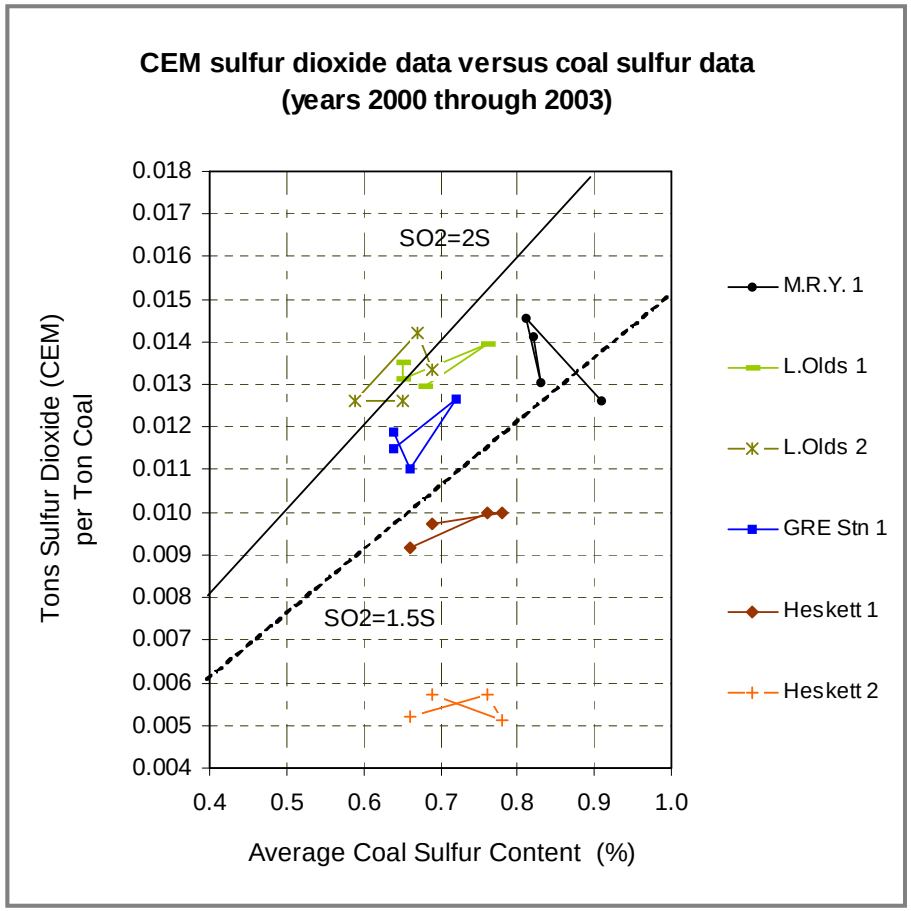

Figure 2. When 100% of coal sulfur is emitted from stacks of plants, SO2 equals 2S. When 75% is emitted, SO2 equals 1.5S and the remaining 25% of S is retained in ash, which is equivalent to EPA's AP-42 emission factor of 30S. See Appendix E of the MOU protocol.

Table 1a. CALMET user defined and non-IWAQM control-file inputs.

Variable	Type	Description	Department's 2003 protocol	Alternative NWS only	Alternative RUC & NWS
NUSTA	integer	number of upper air stations within and surrounding the modeling domain – may change from year to year	6	6	6
1BTZ	integer	base time zone (7 = Mountain Standard)	7	7	7
NX	integer	number of grid cells in X direction	128	128	213
NY	integer	number of grid cells in Y direction	92	92	153
NZ	integer	number of vertical layers	12	12	12
DGRIDKM	real	horizontal/vertical size & spacing of grid cells (km)	5.	5.	3.
XORIGKM	real	reference LCP (Lambert Conformal Projection) X coordinate of southwest grid cell (km)	-380.	-380.	-380.
YORIGKM	real	reference LCP Y coordinate of southwest grid cell (km)	140.	140.	140.
XLAT0	real	latitude at southwest corner of grid cell 1,1 (deg.)	45.152	45.152	45.152
XLON0	real	longitude at southwest corner of grid cell 1,1 (deg.)	106.848	106.848	106.848
ZFACE	real array: NZ + 1	cell face heights (m)	0., 20., 40., 80., 120., 180., 260., 400., 600., 800., 1200., 2000., 4000.	0., 20., 50., 90., 140., 200., 270., 370., 500., 1000., 1700., 2500., 4200.	same as NWS only at left
LLCONF	logical: T = True	if T, use LCP map coordinates and rotate winds from true north to map north	T	T	T
XLAT1	real	latitude for 1st standard parallel for LCP (deg)	46.0	46.0 [1]	46.0 [1, 3]
XLAT2	real	latitude for 2nd standard parallel for LCP (deg)	48.5	48.5 [1]	48.5 [1, 3]
RLON0	real	reference longitude for LCP rotation of input winds (deg)	102.0	102.0 [2]	102.0 [2, 3]

Table 1a. CALMET user defined and non-IWAQM control-file inputs.

Variable	Type	Description	Department's 2003 protocol	Alternative NWS only	Alternative RUC & NWS
RLAT0	real	origin latitude for LCP rotation of input winds (deg)	44.0	44.0 [2]	44.0 [2, 3]
NSSTA	integer	number of surface meteorological stations within and near the modeling domain – may change from year to year	32	32	32
NPSTA	integer	number of precipitation stations within and near the modeling domain – may change from year to year	89	89	89
IKINE	integer	if 0 (IWAQM default), kinematic effects (a wind field option) are not computed	0	0	0
IEXTRP	integer	extrapolate surface winds to upper layers: 4 or -4 (IWAQM default) = use similarity theory; 1or -1 = no extrapolation	–4	–4	–4 **update to –1**
BIAS	real array: one value for each of NZ layers	layer-dependent biases modifying the weights of surface and upper air stations (-1. =<BIAS<=+1.): negative bias reduces weight given upper air data, positive bias reduces weight given surface data, zero bias leaves weights unchanged	Step 1 only: -1.0, -0.9, -0.8, -0.4, 0.0, 0.1, 0.5, 0.8, 1.0, 1.0, 1.0, 1.0	Step 1 only: -1.0, -0.9, -0.7, -0.4, 0.0, 0.3, 0.7, 1.0, 1.0, 1.0, 1.0, 1.0	do not apply
IPROG	integer	if 0, gridded prognostic model field winds are used; if 4, use MM4 as initial guess field; or if 14, use MM5 as initial guess field	0 (only NWS) & 4 (MM/NWS)	0	14
LVARY	logical: T = True, F = False	if F (IWAQM default), interpolation of winds at a grid point does not include met station observations located beyond RMAX1 or RMAX2 or RMAX3	T	F	F
RMAX1	real	max. radius of influence over land in the surface layer (km)	300.	200.	100.
RMAX2	real	max. radius of influence over land in layers aloft (km)	1200.	800.	200.
RMAX3	real	max. radius of influence over water (km)	500.	800.	200.

Table 1a. CALMET user defined and non-IWAQM control-file inputs.					
Variable	**Type**	**Description**	**Department's 2003 protocol**	**Alternative NWS only**	**Alternative RUC & NWS**
TERRAD	real	radius of influence of terrain features (km) (note: slope flow is computed when default for variable ISLOPE is 1)	30.	16. (coordinated with DGRIDKM)	10. (coordinated with DGRIDKM)
R1	real	in the surface layer, the distance (km) from an observation station at which the wind observation and the first guess field are equally weighted	40.	16. **update to 46.**	10. **update to 5.**
R2	real	in the upper layers, applied same as R1	60.	46.	
NINTR2	integer array	number of observational stations used in interpolation to each grid point – IWAQM default is NZ times 99	99	99 for each of NZ layers	99 for each of NZ layers **update to 16**
ISURFT	integer	surface station number used for the surface temperature for the diagnostic wind field module (note: default for variable IDIOPT1 is 0)	1 (Bismarck)	12 (Bismarck)	12 (Bismarck)
IUPT	integer	upper air station number used to compute the domain-scale temperature lapse rate for the diagnostic wind field module (note: default for variable IDIOPT2 is 0)	1 (Bismarck)	1 (Bismarck)	1 (Bismarck)
ZUPT	real	depth (m) through which domain scale temperature lapse rate is computed (IWAQM default = 200 m)	200.	200. **update to 270.**	
ZUPWND	real array	bottom and top of layer through which the initial guess winds are computed (m)	1., 2000.	1., 2500.	not used
ZIMAX	real	maximum over land mixing height (m)	4000.	4000.	4000.
ZIMAXW	real	maximum over water mixing height (m)	4000.	4000.	4000.

Table 1a. CALMET user defined and non-IWAQM control-file inputs.

Variable	Type	Description	Department's 2003 protocol	Alternative NWS only	Alternative RUC & NWS
MNMDAV	integer	see page 2-29 of the user's guide; maximum search distance (in grid cells, one cell = DGRIDKM) in back trajectory averaging of mixing heights & temperatures (note: defaults for variables IAVEZ1 and IAVET are 1)	8	6 **update to 7**	7 **update to 12**
ILEVZI	integer	layer of winds used in upwind averaging of mixing heights (no default specified in the model)	4	3	3
ITPROG	integer	switch: when 0, temperatures based on surface and upper air observations; when 2, temps taken from MM5 data	(not available in version 5.2)	0	**2 (not available in version 5.2)**

footnotes:

1. The first standard parallel at 46 degrees latitude is north of, but near, the southern border of North Dakota; the second standard parallel at 48.5 is south of the northern border of the state; thus, providing a balanced inclusion of the modeling domain.
2. The approximate center of the TRNP/power-plant region is 47.35 degrees latitude and 102 degrees longitude (the LCP map Y-axis parallels true North at RLON0).
3. RUC2[d] was constructed suitable for CALMET ingest as MM5 with the center latitude at 47.35 degrees, the center longitude at 103 degrees, the first standard parallel at 47.34 degrees latitude and the second at 47.36 degrees.

Table 1b. CALPUFF user defined and non-IWAQM control-file inputs.					
Variable	**Type**	**Description**	**Department's 2003 protocol**	**Alternative NWS only**	**Alternative RUC & NWS**
IBCOMP	integer	southwest X-index of computational domain	1	1	1
JBCOMP	integer	southwest Y-index of computational domain	1	4	6
IECOMP	integer	northeast X-index of computational domain	128	122	201
JECOMP	integer	northeast Y-index of computational domain	92	89	148
MSLUG	integer	if 1, near-field puffs are modeled as elongated slugs; if 0 (IWAQM default), near-field puffs are not modeled as slugs	0	0 for all sources	
MTRANS	integer	if 1 (IWAQM default), transitional plume rise modeled	1	1 for all sources	1 for all sources
MTIP	integer	if 1 (IWAQM default), stack tip down wash modeled	1	1 for all sources	1 for all sources
MSHEAR	integer	if 0 (IWAQM default), vertical wind shear above stack tip not modeled in plume rise	0	0 for all sources	0 for all sources
MSPLIT	integer	if 1, allows puff splitting; if 0 (IWAQM default), no puff splitting // set as 0 for all oil & gas production sources	1	1 (0 as noted)	1 (0 as noted)
MDISP	integer	if 2, horizontal and vertical dispersion coefficients calculated using micro meteorological variables	2	2	2
MPDF	integer	if 1, probability distribution function for vertical dispersion under convective conditions used	0	1	1
XLAT	real	reference latitude of the center of the modeling domain used in solar elevation angle calculations (deg)	47.0	47.3	47.3
XLONG	real	reference longitude of the center of the modeling domain (deg)	102.	102.	102.

Table 1b. CALPUFF user defined and non-IWAQM control-file inputs.					
Variable	**Type**	**Description**	**Department's 2003 protocol**	**Alternative NWS only**	**Alternative RUC & NWS**
XTZ	real	reference time zone of the center of the modeling domain	7.	7.	7.
LSAMP	logical; F = False T = True	if F (IWAQM default), an internally calculated array of gridded receptors is not used [may set to T for select sensitivity tests, boundaries of the array would include all state Class I areas]	F	F	F
IVEG	integer	set to 2 when vegetation in unirrigated areas is active and stressed (IWAQM default = 1 when active and unstressed)	1	2	2
MOZ	integer	if 1 (IWAQM default), use hourly ozone concentrations from OZONE.DAT file	1	1	1
BCKO3	real	default background ozone concentration (ppb)	30.	30.	30.
BCKNH3	real	background ammonia concentration (ppb)	2.	2.	2.
SYTDEP	real	horizontal size of puff (m) beyond which Heffter (1965) time dependent dispersion applies (IWAQM default = 550.)	550.	550. [1]	
SL2PF	real	see also MSLUG; slug to puff transition criterion, which is sigma-y / length of slug (u dt); IWAQM default = 10. (note: default for variable XMXLEN is 1.0 grid cells)	10.	10. **update to 0.2 when MSLUG = 1**	
XSAMLEN	real	maximum travel distance of puff (in grid units, one unit equals DGRIDKM) during one sampling step	0.5	0.6	1.0
XMAXZ1	real	maximum mixing height (m)	4000.	4000.	4000.
IRESPLIT	integer array	when set to 1, allows puff splitting for those hour(s) of day when nocturnal shear (e.g., low-level jet) occurs; other hours set to 0	hours 18-23 = 1	hours 00–04 and 19–23 = 1	hours 00–04 and 19–23 = 1

Table 1b. CALPUFF user defined and non-IWAQM control-file inputs.

Variable	Type	Description	Department's 2003 protocol	Alternative NWS only	Alternative RUC & NWS
ZISPLIT	real	vertical puff splitting allowed only when last hour's mixing height (m) exceeds this value; IWAQM default = 100. (note: default value for CALMET variable ZIMIN is 50 m)	100.	100. not coordinated with HSTAK & ZFACE **update to 150.**	
ROLDMAX	real	vertical puff splitting allowed only when the ratio of last hour's mixing height to max. mixing height experienced by the puff is smaller than this value (IWAQM default = 0.25)	0.25	0.33 when coordinated with ZISPLIT, previous max. mix. height =or> 300 m	
NSPLIT	integer	see also MSPLIT, IRESPLIT, ZISPLIT, ROLDMAX and section 2.2.4 of the user's guide; number of new puffs when existing puff is split (IWAQM default = 3)	3	3 not coordinated with HSTAK & ZFACE **update to 4**	
BDOWN	real	if 0, building down wash is not modeled	0.	0.	0.
SIGMAYI	real	initial plume (puff) sigma-y at release from source (m); if < 1.0, CALPUFF code resets to 1.0 // omit for oil & gas production sources (CALPUFF code defaults to 1.0)	0. for all sources	1/4 the stack diameter (omit as noted)	1/4 the stack diameter (omit as noted)
NREC	integer	number of non-gridded receptors	86	104	104

footnotes:
1. "Assuming PG dispersion rates under neutral conditions, a plume's σ_y [lateral dimension] will reach 550 m after approximately 10 km of travel distance." (User's guide, page 2-29.)

Table 2a. Calculated sulfur dioxide emission factors using 2000 and 2001 coal and emissions data.

Company / Plant	Current Boiler Type	Parameter *	Year 2000	Year 2001	Calculated Emission Factors ** (lb / ton)	Energy Research Lab. *** (lb / ton)	Alternative Baseline Emission Factor (lb / ton)
MDU / Heskett Unit 1	spreader stoker	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	111,114 0.66 1,019	102,134 0.76 1,022	2000 - 27.8 2001 - 26.3 (ave. = 27.0)		27.0
MDU / Heskett Unit 2	fluidized-bed	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	340,598 0.66 1,778	458,243 0.76 2,625	2000 - 15.8 2001 - 15.1 (ave. = 15.4)		27.0 (same as Unit 1)
Basin Electric / Leland Olds Unit 1	pulverized wall-fired	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	1,302,256 0.68 16,864	1,093,610 0.76 15,237	2000 - 38.1 2001 - 36.7 (ave. = 37.4)	33.4	37.4
Basin Electric / Leland Olds Unit 2	cyclone	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	2,140,601 0.69 28,587	2,546,797 0.67 36,219	2000 - 38.7 2001 - 42.5 (ave. = 40.7)		38.7 (yr 2000)
Minnkota / M.R. Young Unit 1	cyclone	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	1,434,793 0.91 18,095	1,590,495 0.81 23,179	2000 - 27.7 2001 - 36.0 (ave. = 31.8)	33.3	33.3
Great River Energy / Stanton Unit 1	pulverized wall-fired	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	666,577 0.64 7,660	744,341 0.72 9,424	2000 - 35.9 2001 - 35.2 (ave. = 35.5)		35.5

* Amounts of coal burned and average sulfur content of that coal taken from annual emissions inventory reports. Amounts of emitted sulfur dioxide from CEM data as archived on EPA's Acid Rain Program data base.

** Calculated emission factor equals sulfur dioxide emissions (as measured by CEM) divided by the product of the average sulfur content and the amount of coal burned.

*** Gronhovd, G.H., et.al., May 1973, Some Studies on Stack Emissions from Lignite-Fired Power Plants, 1973 Lignite Symposium, May 9-10, 173, Grand Forks, North Dakota.

Table 2b. Calculated sulfur dioxide emission factors using 2002 and 2003 coal and emissions data.

Company / Plant	Current Boiler Type	Parameter *	Year 2002	Year 2003	Calculated Emission Factors ** (lb / ton)		2000–2003 Average Emission Factor (lb / ton)
MDU / Heskett Unit 1	spreader stoker	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	62,208 0.78 622	111,443 0.69 1,083	2002 – 25.6 2003 – 28.2		27.1
MDU / Heskett Unit 2	fluidized-bed	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	428,358 0.78 2,189	462,469 0.69 2,649	2002 – 13.1 2003 – 16.6		15.1
Basin Electric / Leland Olds Unit 1	pulverized wall-fired	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	1,267,512 0.65 16,655	1,413,422 0.65 19,125	2002 – 40.4 2003 – 41.6		39.2
Basin Electric / Leland Olds Unit 2	cyclone	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	2,438,957 0.59 30,744	2,031,422 0.65 25,598	2002 – 42.7 2003 – 38.8		40.8
Minnkota / M.R. Young Unit 1	cyclone	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	1,520,552 0.83 19,858	1,276,687 0.82 18,020	2002 – 31.5 2003 – 34.4		32.3
Great River Energy / Stanton Unit 1	pulverized wall-fired	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	808,083 0.66 8,900	679,593 0.64 8,084	2002 – 33.4 2003 – 37.2		35.3

* Amounts of coal burned and average sulfur content of that coal taken from annual emissions inventory reports. Amounts of emitted sulfur dioxide from CEM data as archived on EPA's Acid Rain Program data base.
** Calculated emission factor equals sulfur dioxide emissions (as measured by CEM) divided by the product of the average sulfur content and the amount of coal burned.

Table 3a. Sulfur dioxide emission rates of sources operating at the time of the PSD minor source baseline date.

	Source	Unit	Basis	Baseline period	Ave. per.	2003 Protocol	MOU Protocol	Units	
	Beulah Power Plant	1 & 2	e.i.r.	76 - 77	an.ave.	137.1	127.0	lb/op-hr	#
Sources operating at PSD baseline and retired prior to current period.		3, 4 & 5	e.i.r.	76 - 77	an.ave.	224.6	203.6	lb/op-hr	#
	Neal Station	1 & 2	e.i.r.	76 - 77	an.ave.	354.6	364.6	lb/op-hr	#
	Royal Oak Briquetting	Boilers 1, 2 & 3	e.i.r.	78 - 79	an.ave.	172.1	220.8	lb/op-hr	
	Plant	Carbonizer Furnaces	e.i.r.	78 - 79	an.ave.	1,542.0	1,124.8	lb/op-hr	#
	Williston Refinery	All units	e.i.r.	76	an.ave.	51.7	51.7	lb/op-hr	
		Preflash Heater		76	an.ave.	7.1	7.1	lb/op-hr	
		Crude Heater		76	an.ave.	7.7	7.7	lb/op-hr	
		Thermal Cr. Heater		76	an.ave.	0.3	0.3	lb/op-hr	
		Charge Heater		76	an.ave.	0.1	0.1	lb/op-hr	
		Reformer Heater		76	an.ave.	0.5	0.5	lb/op-hr	
		Boiler 1		76	an.ave.	10.5	10.5	lb/op-hr	
		Boiler 2		76	an.ave.	10.5	10.5	lb/op-hr	
		Boiler 3		76	an.ave.	15.0	15.0	lb/op-hr	
	R.M. Heskett Station	1	e.i.r.	76 - 77	an.ave.	466.0	415.8	lb/op-hr	#
Sources operating at PSD baseline and also operating during current period.		2	e.i.r.	76 - 77	an.ave.	1,087.2	969.9	lb/op-hr	#
	Leland Olds Station	1	e.i.r.	77 - 78	an.ave.	3,990.1	3,609.8	lb/op-hr	#
		2	e.i.r.	77 - 78	an.ave.	8,106.2	7,312.4	lb/op-hr	#
	M.R. Young Station	1	e.i.r.	78 - 79	an.ave.	4,959.9	4,357.0	lb/op-hr	#
		2	e.i.r.	78 - 79	an.ave.	4,905.6	4,726.5	lb/op-hr	+
	Stanton Station	1	e.i.r.	78 - 79	an.ave.	2,487.5	2,271.3	lb/op-hr	#
	Tioga Gas Plant	SRU Incinerator	e.i.r.	77	an.ave.	1,107.1	1,107.1	lb/op-hr	
	Lignite Gas Plant	SRU Incinerator	e.i.r.	76 - 77	an.ave.	285.8	285.8	lb/op-hr	
	Mandan Refinery	Boilers 1, 2 & 3	e.i.r.	76 - 77	an.ave.	1,172.7	622.6	lb/op-hr	
		Crude Furnace	e.i.r.	76 - 77	an.ave.	with boilers	550.1	lb/op-hr	
		FCCU	e.i.r.	76 - 77	an.ave.	1,135.8	1,135.8	lb/op-hr	
		Alkylation Unit	e.i.r.	76 - 77	an.ave.	160.3	160.3	lb/op-hr	
		Ultraformer Furnaces	e.i.r.	76 - 77	an.ave.	15.3	15.3	lb/op-hr	
	Total all rates =					32,413.3	29,683.9		

e.i.r. = annual emissions inventory reports

lb/op-hr = pounds per operating hour

Ave. per. = averaging period

= rate based on source specific emission factor (Appendix E)

an.ave. = actual emissions during operating hours

+ = rate based on annual heat input and permit allowed rate of 1.2 lbSO2/mBtu

Table 3b. Sulfur dioxide emission rates (lb/op-hr) of sources for years 2000, 2001, 2002 and 2003; and actual emissions (lb/op-hr) of the sources for 2000--2001 and 2002--2003.

	Source	Unit	Basis	2003 Protocol	MOU Protocol 2000	MOU Protocol 2001	MOU Protocol 00-01 #	Updated rates 2002	Updated rates 2003	Updated rates 02-03 #	fn
Sources operating at PSD baseline and also operating during current period.	R.M. Heskett Station	1	e.i.r., CEM	248.0	246.8	249.2	248.0	220.1	256.4	241.8	
		2	e.i.r., CEM	612.7	584.6	634.4	612.7	536.3	669.7	602.0	
	Leland Olds Station	1	e.i.r., CEM	4,179.2	4,088.2	4,292.1	4,179.2	3,948.6	4,457.5	3,833.0	fn 3
		2	e.i.r., CEM	8,566.0	8,293.3	8,808.1	8,145.1	7,721.7	7,866.6	7,379.7	fn 3
	M.R. Young Station	1	e.i.r., CEM	5,161.4	4,806.7	5,479.0	5,161.4	4,782.8	4,831.7	4,805.9	
		2	e.i.r., CEM	4,353.2	5,033.0	3,521.7	4,353.2	2,131.2	2,450.5	2,291.2	
	Stanton Station	1 & 10	e.i.r., CEM	2,389.8	2,314.5	2,416.7	2,389.8	2,254.6	2,566.1	2,443.5	
	Tioga Gas Plant	SRU Incinerator	CEM	300.6	295.9	305.2	300.6	350.2	296.2	322.6	
	Lignite Gas Plant	SRU Incinerator	CEM	0.0	105.6	ditto	105.6	0.0	0.0	0.0	fn 1
	Mandan Refinery	Boilers + Crude Furnace	e.i.r.	133.0	227.9	37.1	133.0	52.1	81.2	66.1	
		FCCU	e.i.r.	1,026.9	970.5	1,084.5	1,026.9	913.9	1,033.9	971.0	
		Alkylation Unit	e.i.r.	7.7	7.3	8.1	7.7	10.1	8.6	9.4	
		Ultraformer Furnaces	e.i.r.	15.9	15.1	17.2	15.9	13.1	14.2	13.6	
		SRU Incinerator	e.i.r.	45.3	42.1	48.4	45.3	58.6	60.2	59.4	
Sources constructed after PSD baseline and operating during current period.	Coal Creek Station	1	CEM	3,368.1	3,319.1	3,423.4	3,368.1	3,034.0	3,223.0	3,132.7	
		2	CEM	2,972.8	3,041.2	2,910.6	2,972.8	2,888.0	3,142.8	3,015.0	
	Antelope Valley Station	1	CEM	1,590.8	1,597.5	1,585.5	1,590.8	1,744.9	1,770.3	1,758.2	
		2	CEM	1,496.0	1,503.8	1,488.7	1,496.0	1,709.1	1,786.9	1,748.1	
	Coyote Station	1	CEM	3,955.4	3,906.6	4,025.5	3,955.4	3,475.5	3,643.1	3,553.7	
	Grasslands Gas Plant	SRU Incinerator	CEM	0.0	113.4	ditto	113.4	0.0	0.0	0.0	fn 2
	Little Knife Gas Plant	SRU Incinerator	CEM	80.1	82.1	77.9	80.1	63.0	70.7	66.8	
	Great Plains Synfuels	Main stack	CEM	1,094.4	1,247.0	941.8	1,094.4	826.1	751.6	788.6	
		Start-up flare	allowable	119.0	119.0	119.0	119.0	21.8	11.0	16.2	
		Main flare	e.i.r.	184.0	177.3	190.6	184.0	96.5	236.3	166.4	
		Back-up flare	allowable	78.0	78.0	78.0	78.0	26.6	109.7	34.8	
	Red Trail Energy	Boiler stack	allowable	na		construction site dirt work initiated fall 2004				2.83	
	PPL Corp Colstrip	3	CEM	742.9	742.9	742.9	742.9	769.4	776.2	773.4	
		4	CEM	719.0	719.0	719.0	719.0	744.3	759.0	751.0	
	CELP Colstrip		CEM	419.8	419.8	419.8	419.8	302.9	302.9	302.9	
	Total all rates =			43,860.1	44,098.2	43,624.4	43,658.2	38,695.4	41,176.3	39,149.8	

lb/op-hr = pounds per operating hour

e.i.r. = annual emissions inventory reports

= actual emissions per rule definition

fn1 = began injecting sour gas during August 2002

fn2 = began injecting sour gas during March 2002

fn3 = see Appendix E of the MOU protocol

Figure 4a. PSD baseline-period source locations and stack operating data.

Source	Unit	Longitude (degrees)	Latitude (degrees)	Stack height (m)	Base elevation (m)	Stack diameter (m)	Exit velocity (m/s)	Exit temp. (deg. K)
Beulah Power Plant	1 & 2	-101.77088	47.26346	23.0	567.0	1.7	7.6	477.0
	3, 4 & 5	-101.77088	47.26346	30.5	567.0	2.1	14.6	527.0
Neal Station	1 & 2	-100.88236	48.02377	42.4	488.0	1.8	25.0	470.0
Royal Oak Briquetting	Boilers 1, 2 & 3	-102.70032	46.85862	19.2	751.0	1.4	9.8	520.0
Plant	Carbonizer Furnaces	-102.69941	46.86010	26.2	751.0	3.4	9.4	1,172.0
Williston Refinery	Heaters + boiler 2	-103.58690	48.14555	17.3	575.0	0.9	3.2	700.0
	Boiler 1	-103.58690	48.14555	30.2	575.0	1.2	3.4	464.0
	Boiler 3	-103.58690	48.14555	9.1	575.0	0.8	6.3	464.0
R.M. Heskett Station	1	-100.88383	46.86719	91.4	514.8	2.2	20.7	461.7
	2	-100.88350	46.86641	91.4	514.8	3.7	17.4	419.7
Leland Olds Station	1	-101.32125	47.28140	106.7	518.3	5.3	19.7	450.0
	2	-101.31991	47.28080	152.4	518.3	6.7	25.0	448.6
M.R. Young Station	1	-101.21445	47.06700	91.4	597.4	5.8	18.5	449.1
	2	-101.21470	47.06625	167.6	597.4	7.6	19.2	361.8
Stanton Station	1	-101.33205	47.28650	77.7	518.3	4.6	19.9	411.1
Tioga Gas Plant	SRU Incinerator	-102.91625	48.39835	30.5	686.0	1.7	7.7	782.0
Lignite Gas Plant	SRU Incinerator	-102.54183	48.87317	38.1	598.0	0.4	19.9	893.0
Mandan Refinery	Boilers 1, 2 & 3	100.87838	46.85124	31.8	518.3	1.7	12.5	424.7
	FCU + Crude Furnace	-100.88038	46.85198	60.7	518.3	3.4	9.9	547.0
	Alkylation Unit	-100.87780	46.85614	53.0	518.3	2.0	6.1	447.0
	Ultraformer Furnaces	-100.87783	46.85328	29.1	518.3	1.3	5.9	530.8

Figure 4b. PSD current-period souce locations and stack operating data.

Source	Unit	Longitude (degrees)	Latitude (degrees)	Stack height (m)	Base elevation (m)	Stack diameter (m)	Exit velocity (m/s)	Exit temp. (deg. K)
R.M. Heskett Station	1	-100.88383	46.86719	91.4	514.8	2.2	20.7	461.7
	2	-100.88350	46.86641	91.4	514.8	3.7	17.4	419.7
Leland Olds Station	1	-101.32125	47.28140	106.7	518.3	5.3	19.7	450.0
	2	-101.31991	47.28080	152.4	518.3	6.7	25.0	448.6
M.R. Young Station	1	-101.21445	47.06700	91.4	597.4	5.8	18.5	449.1
	2	-101.21470	47.06625	167.6	597.4	7.6	19.2	361.8
Stanton Station	1 & 10	-101.33205	47.28650	77.7	518.3	4.6	19.9	411.1
Tioga Gas Plant	SRU Incinerator	-102.91625	48.39835	50.3	686.0	0.9	7.7	782.0
Mandan Refinery	Boilers 1, 2 & 3	100.87838	46.85124	31.8	518.3	1.7	12.5	424.7
	FCCU + Crude Furnace	-100.88038	46.85198	60.7	518.3	3.4	9.9	547.0
	Alkylation Unit	-100.87780	46.85614	53.0	518.3	2.0	6.1	447.0
	Ultraformer Furnaces	-100.87783	46.85328	29.1	518.3	1.3	5.9	530.8
	SRU Incinerator	-100.87766	46.85201	60.8	518.3	0.6	5.7	589.0
Coal Creek Station	1	-101.15782	47.37854	201.0	602.0	6.7	25.9	358.5
	2	-101.15642	47.37858	201.0	602.0	6.7	24.9	354.5
Antelop Valley Station	1	-101.83534	47.37004	182.9	588.3	7.0	19.0	358.2
	2	-101.83556	47.37096	182.9	588.3	7.0	19.1	356.7
Coyote Station	1	-101.81480	47.22105	152.0	556.9	6.4	25.4	370.7
Little Knife Gas Plant	SRU Incinerator	-103.09806	47.29667	59.5	780.5	1.8	1.5	744.7
Great Plains Synfuels	Main stack	-101.84050	47.36160	119.8	588.3	7.0	12.1	357.1
	Start-up flare	-101.83886	47.36420	68.6	588.3	0.5	98.4	1,000.0
	Main flare	-101.83581	47.35576	76.2	588.3	1.0	100.5	1,000.0
	Back-up flare	-101.83900	47.36370	30.5	588.3	0.5	102.1	1,000.0
Red Trail Energy	Boiler stack	-102.30	46.88	39.6	753.7	2.4	11.7	579.6
PPL Corp Colstrip	3	-106.6239	45.8842	210.9	988.7	7.3	26.9	361.3
	4	-106.6236	45.8842	210.9	988.7	7.3	27.6	362.7
CELP Colstrip		-106.6545	45.9748	61.0	945.1	2.5	22.6	433.2

Table 5. Observed and modeled 24-hour concentrations at the site of the monitor in the South Unit of TRNP.

(Units for concentrations are ug/m3. A background concentration of 1.5 ug/m3 has been added to modeled concentrations.

			MOU protocol (1)		Select modified input values (1)		MOU protocol (2)	
Rank	Observed		Pred+1.5	P / O	Pred+1.5	P / O	Pred+1.5	P / O
1	12.44		17.22	1.38	17.74	1.43	16.70	1.34
2	8.30		16.37	1.97	16.77	2.02	15.65	1.89
3	7.97		11.61	1.46	12.60	1.58	11.50	1.44
4	7.31		10.57	1.45	10.38	1.42	10.44	1.43
5	6.99		10.23	1.46	9.96	1.42	10.17	1.45
6	6.88		9.63	1.40	9.93	1.44	9.77	1.42
7	6.44		9.25	1.44	9.03	1.40	9.48	1.47
8	6.22		9.01	1.45	9.02	1.45	8.94	1.44
9	6.22		8.60	1.38	8.69	1.40	8.55	1.37
10	5.89		8.56	1.45	8.14	1.38	8.48	1.44
11	5.79		8.38	1.45	7.98	1.38	8.31	1.44
12	5.68		7.36	1.30	7.24	1.27	7.09	1.25
13	5.68		7.10	1.25	6.95	1.22	7.04	1.24
14	5.46		6.45	1.18	6.39	1.17	6.39	1.17
15	5.46		6.26	1.15	6.29	1.15	6.18	1.13
16	5.46		5.90	1.08	5.86	1.07	5.85	1.07
17	5.46		5.85	1.07	5.83	1.07	5.74	1.05
18	5.46		5.78	1.06	5.63	1.03	5.68	1.04
19	5.35		5.56	1.04	5.48	1.02	5.52	1.03
20	5.24		5.48	1.05	5.46	1.04	5.51	1.05
21	5.24		5.45	1.04	5.42	1.03	5.49	1.05
22	5.24		5.30	1.01	5.35	1.02	5.35	1.02
23	5.13		5.09	0.99	5.21	1.02	5.08	0.99
24	5.13		5.08	0.99	5.07	0.99	5.03	0.98
25	5.13		5.06	0.99	4.96	0.97	4.85	0.95
average				1.26		1.26		1.25

(1) = CALMET version 5.2 and CALPUFF version 5.4. (2) = CALMET version 5.5 and CALPUFF version 5.7.

Table 6. Observed and modeled 24-hour sulfur dioxide concentrations at the site of the monitor in the South Unit of TRNP.

(Units for concentrations are ug/m3. A background concentration of 1.5 ug/m3 has been added to modeled concentrations.

		Year 2000 RUC2d			Year 2001 RUC2d			Year 2002 RUC2d		
		2000-01 actual emissions		baseline emissions	2000-01 actual emissions		baseline emissions	2002-03 actual emissions		baseline emissions
	Rank	Observed	Pred+1.5	Pred+1.5	Observed	Pred+1.5	Pred+1.5	Observed	Pred+1.5	Pred+1.5
	1	9.72	13.17	10.54	10.37	9.23	7.19	12.44	17.83	14.78
After omission of the highest (rank of 1), the next eighteen are 5% of the 365 days during the year.	2	9.39	9.46	8.68	8.81	8.87	6.95	8.30	16.97	14.77
	3	7.42	9.41	8.55	8.62	7.80	6.92	7.97	12.07	10.75
	4	6.55	9.20	8.04	8.41	7.67	6.67	7.31	10.95	10.03
	5	6.11	9.13	7.63	7.38	7.28	5.87	6.99	10.65	9.32
	6	5.95	9.04	7.52	6.55	6.98	5.82	6.88	10.02	8.79
	7	5.79	8.62	6.60	5.79	6.70	5.72	6.44	9.56	8.59
	8	5.68	8.37	6.49	5.79	5.58	5.71	6.22	9.32	7.86
	9	5.57	7.78	6.42	5.60	5.54	5.65	6.22	8.90	7.65
	10	5.57	7.38	6.38	5.46	5.49	5.19	5.89	8.88	7.56
	11	5.35	6.74	6.26	5.35	4.84	5.17	5.79	8.68	7.01
	12	5.24	6.21	6.19	5.24	4.76	4.93	5.68	7.58	6.89
	13	5.13	5.79	6.04	5.02	4.53	4.80	5.68	7.29	6.49
	14	4.80	5.42	5.97	4.91	4.44	4.62	5.46	6.68	6.16
	15	4.69	5.38	5.95	4.88	4.41	4.58	5.46	6.48	6.02
	16	4.59	5.06	5.88	4.80	4.23	4.57	5.46	6.06	5.87
	17	4.59	4.83	5.54	4.80	4.14	4.52	5.46	6.03	5.87
	18	4.59	4.75	5.32	4.59	4.13	4.25	5.46	5.96	5.81
	19	4.59	4.68	5.21	4.48	4.00	4.24	5.35	5.72	5.67
	20	4.48	4.65	4.99	4.37	3.92	4.07	5.24	5.65	5.42
	21	4.26	4.57	4.96	4.37	3.89	3.99	5.24	5.59	5.34
	22	4.26	4.32	4.75	4.37	3.86	3.91	5.24	5.43	5.34
	23	4.26	4.26	4.72	4.15	3.85	3.79	5.13	5.23	5.32
	24	4.15	4.12	4.69	4.15	3.83	3.76	5.13	5.23	5.15
	25	4.04	4.09	4.45	4.04	3.80	3.75	5.13	5.21	5.14
	18-day mean	5.64	7.07	6.59	5.92	5.63	5.34	6.22	8.77	7.84

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